A COURSE IN

MECHANICAL DRAWING.

BY

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PREFACE TO THE THIRD EDITION.

To MEET the demands of high schools, manual training high schools, university preparatory schools, technical colleges, and evening classes, it has been found necessary to add to "A Course in Mechanical Drawing" a concrete set of problems covering the full requirements in mechanical drawing for entrance to the more advanced classes in machine drawing, elementary machine design, and architectural drawing. The minimum time allowed in a definite number of working hours for the finishing of each plate, as introduced in this edition, is a new feature, and will be much appreciated by Instructors when determining the amount of work to require from their students in a given term. The time allowed for the different plates has been carefully determined by taking note of the actual number of hours taken by large numbers of students working on the same plates, under the same conditions, and a conservative average taken, so that any young man of fair intelligence and with an honest endeavor may finish any of the plates in the time given.

The Course in Lettering, which has also been added to this edition, will be found to be of great practical benefit to students in all kinds of engineering drafting, and will be seen to embrace

the most approved practice in drafting room methods at the present time.

The report on the "Present Practice in Drafting Room Methods," which will be found at the end of the book, is also new and will interest Instructors and enable them to adopt a system in their drawing courses that may closely approximate the best practice in the leading and most progressive drafting rooms in the United States.

The thanks of the author are due and are most cordially extended to those who have used this book in the past and have encouraged and assisted him by gracious words and timely suggestions.

JOHN S. REID.

ARMOUR INSTITUTE OF TECHNOLOGY,
Chicago, Ill., September, 1908.

PREFACE.

In the course of a large experience as an instructor in drawing and designing, the author of this work has often been called upon to teach the elements of mechanical drawing to students in marine, electrical, railway, and mechanical engineering. Having tried and failed to find a book on the subject that was entirely suitable for his use as a text-book, he has found it necessary to prepare the present work.

This course contains, in the author's judgment, a complete and concise statement, accompanied by examples, of the essential principles of mechanical drawing—all that any young man of ordinary intelligence needs to master, by careful study, the more advanced problems met with in machine construction and design. Such works as the author has tried, although most excellent from certain standpoints, were either incomplete in some of the divisions of the subject or too voluminous and elementary in the treatment of details.

The author does not imagine this work is perfect, but he believes that it comes nearer what is needed in teaching the elements of mechanical drawing in technical schools, high schools, evening drawing schools, and colleges than any work he has examined.

The chapter on Conventions will be appreciated by students

when called upon to execute working drawings in practical work. The methods described are considered by the author to be those which have met with general approval by the experienced American draftsmen of the present time.

My acknowledgments are due to E. C. Cleaves, professor of drawing, Sibley College, Cornell University, for reading the manuscript and making some valuable suggestions.

THE AUTHOR.

April 1, 1898.

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MECHANICAL DRAWING.

INTRODUCTION.

A NEED has been felt by instructors and students, especially in technical courses, for a text-book that would illustrate the fundamental principles of mechanical drawing in such a practical, lucid, direct and progressive way as to enable the instructor to teach, and the student to acquire, the greatest number of the essential principles involved, and the ability to apply them, in a draftsman-like manner, in the shortest space of time.

With this in mind, the present work has been prepared from the experience of the writer, a practical draftsman and teacher for over fifteen years.

THE COMPLETE OUTFIT.

The outfit for students in mechanical and machine drawing is as follows:

(1) THE DRAWING-BOARD for academy and freshman work is $16'' \times 21'' \times \frac{1}{2}''$, the same as that used for free-hand drawing. The material should be soft pine and constructed as shown by Fig. 1.

(2) 1 SCRIBBLING PENCIL with rubber tip.

(3) PENCILS, one 6H and one 4H Koh-i-noor or Faber.

(4) The T-SQUARE; a plain pearwood T-square with a fixed head is all that is necessary. Length 21″.

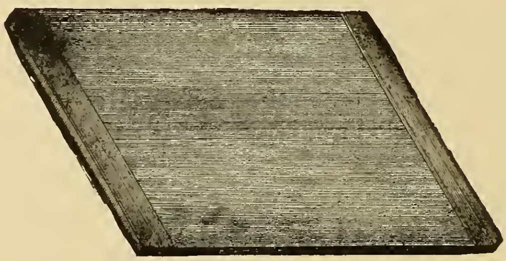


FIG. 1.

(5) INSTRUMENTS. "Pocket Book" Set, shown by Fig. 2, recommended as a first-class medium-priced set of instruments. It contains

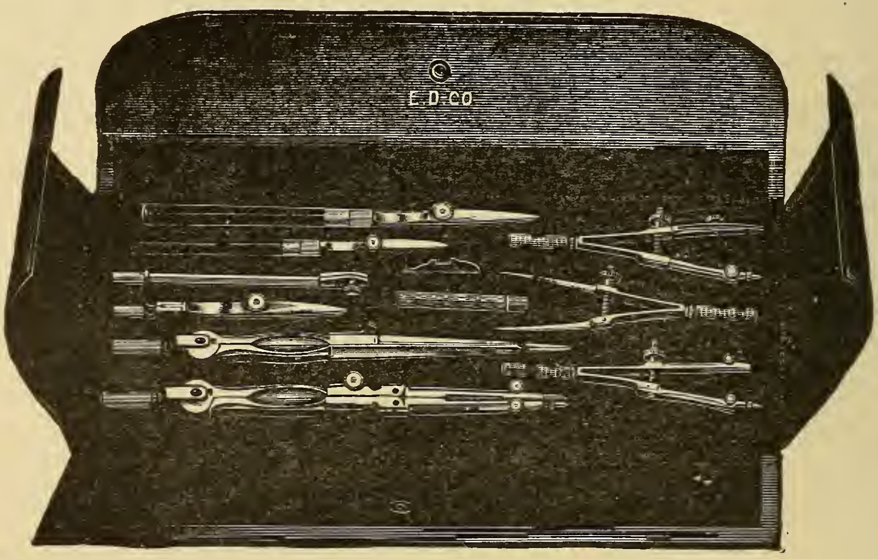


FIG. 2.

A COMPASS, $5\frac{1}{2}''$ long, with fixed needle-point, pencil, pen and lengthening bar; a SPRING BOW PENCIL, 3″ long; a SPRING BOW PEN, 3″ long; a SPRING BOW SPACER, 3″ long;

2 Drawing-pens, medium and small, 1 Hair-spring Divider, 5″ long; a nickel-plated box with leads.

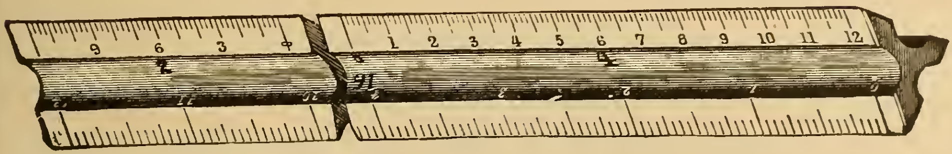


Fig. 3.

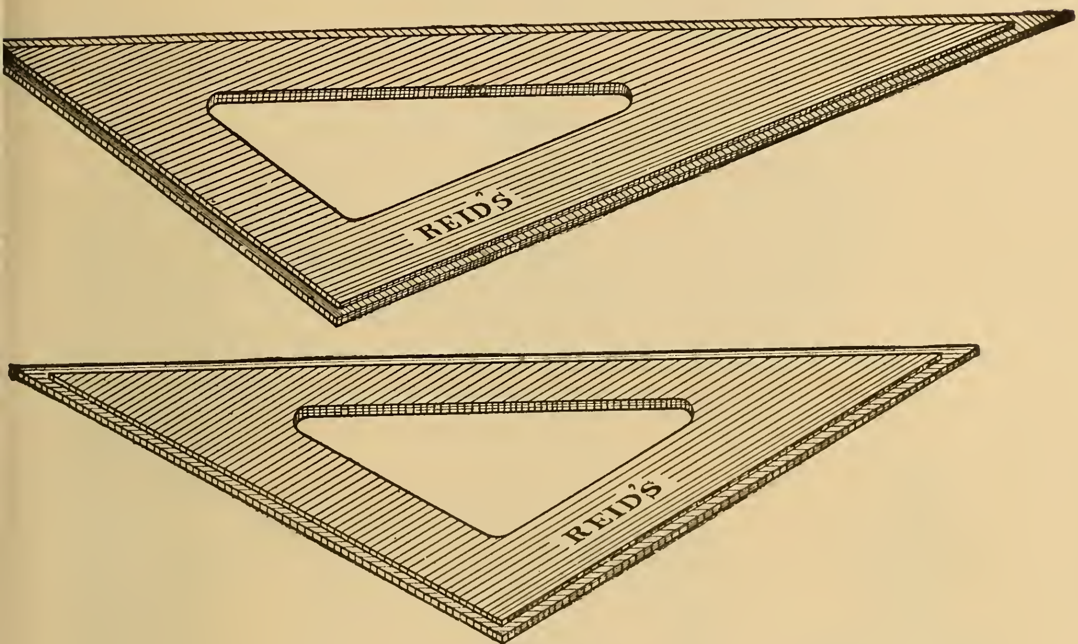


Fig. 4.

Fig. 5.

(6) A Triangular Boxwood Scale graduated as follows: 4″ and 2″, 3″ and $1\frac{1}{2}$″, 1″ and $\frac{1}{2}$″, $\frac{3}{4}$″ and $\frac{3}{8}$″, $\frac{1}{16}$″ and $\frac{1}{32}$″.

(7) 1 Triangle 30°×60°, celluloid, 10″ long. Fig. 4.

1 " 45°, " 7″ " "

(8) 1 Irregular Curve. No. 13. Fig. 5.

(9) Emery Pencil Pointer.

(10) Ink, black waterproof. Fig. 7.

(11) Ink Eraser. Faber's Typewriter. No. 104.

(12) Pencil Eraser, "Emerald" No. 211. Fig. 9.

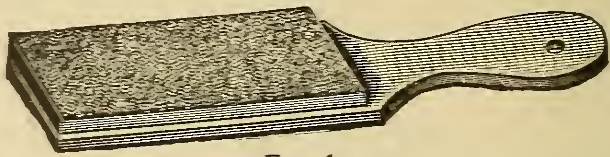


Fig. 6.

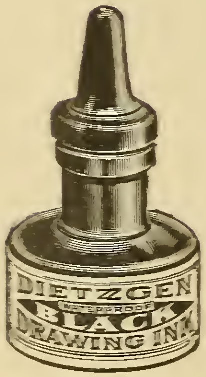


Fig. 7.

Fig. 8.

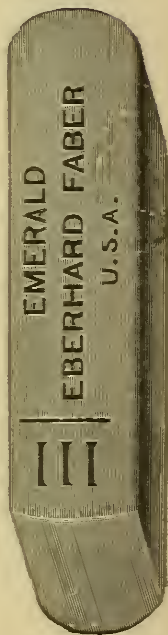


Fig. 9.

(13) Sponge Rubber or Cube of "Artgum." Figs. 10, 11.

(14) Tacks, a small carton of 1 oz. copper tacks, and 1 doz. small thumb tacks.

(15) Arkansas Oil Stone. $2'' \times \frac{1}{2}'' \times \frac{1}{16}''$.

(16) Protractor. German silver, about 5″ diam. Fig. 12.

(17) Scale Guard, " " Fig. 13.

(18) 2 sheets of "CREAM" DRAWING PAPER. 15″×20″.

(19) 2 " " IMPERIAL TRACING CLOTH. 15″×20″.

(20) 1 CROSS-SECTION PAD. 8″×10″.

(21) 1 SCRIBBLING PAD.

FIG. 10.

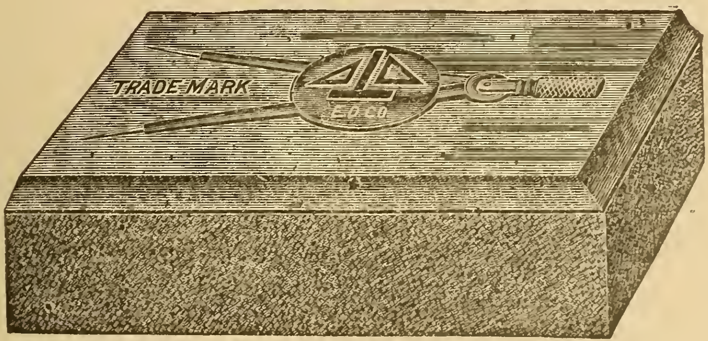


FIG. 11.

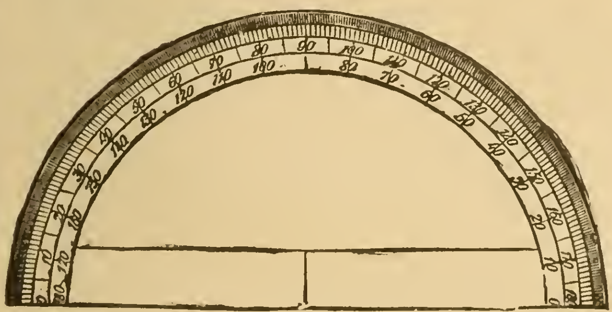


FIG. 12.

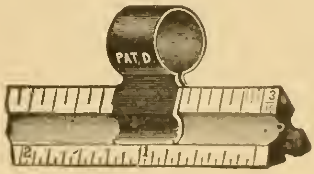


FIG. 13.

(22) 1 ERASING SHIELD, nickel plated.

(23) 2 LETTERING PENS, "Gillott" No. 303.

(24) 2 " " "Ball Point," No. 506.

(25) 2 " " " " No. 516.

(26) 1 TWO-FOOT RULE

CHAPTER I.

INSTRUMENTS.

It is a common belief among students that any kind of cheap instrument will do with which to learn mechanical drawing, and not until they have acquired the proper use of the instruments should they spend money in buying a first-class set. This is one of the greatest mistakes that can be made. Many a student has been discouraged and disgusted because, try as he would, he could not make a good drawing, using a set of instruments with which it would be difficult for even an experienced draftsman to make a creditable showing.

If it is necessary to economize in this direction it is better and easier to get along with a fewer number, and have them of the best, than it is to have an elaborate outfit of questionable quality.

The instruments shown in Fig. 2 are well made of a moderate price, and with care and attention will give good satisfaction for a long time.

USE OF INSTRUMENTS.

The Pencil.—Designs of all kinds are usually worked out in pencil first, and if to be finished and kept they are inked in and sometimes colored and shaded; but if the drawing is only to be finished in pencil, then all the lines except construction, center, and dimension lines should be made broad and dark,

so that the drawing will stand out clear and distinct. It will be noticed that this calls for two kinds of pencil-lines, the first a thin, even line made with a hard, fine-grained lead-pencil, not less than 6H (either Koh-i-noor or Faber's), and sharpened to a knife-edge in the following manner: The lead should be carefully bared of the wood with a knife for about $\frac{1}{2}''$, and the wood neatly tapered back from that point; then lay the lead upon the emery-paper sharpener illustrated in the outfit, and carefully rub to and fro until the pencil assumes a long taper from the wood to the point; now turn it over and do the same with the other side, using toward the last a slightly oscillating motion on both sides until the point has assumed a sharp, thin, knife-edge endwise and an elliptical contour the other way.

This point should then be polished on a piece of scrap drawing-paper until the rough burr left by the emery-paper is removed, leaving a smooth, keen, ideal pencil-point for drawing straight lines.

With such a point but little pressure is required in the hands of the draftsman to draw the most desirable line, one that can be easily erased when necessary and inked in to much better advantage than if the line had been made with a blunt point, because, when the pencil-point is blunt the inclination is to press hard upon it when drawing a line. This forms a groove in the paper which makes it very difficult to draw an even inked line.

The second kind of a pencil-line is the broad line, as explained above; it should be drawn with a somewhat softer pencil, say 4H, and a thicker point.

All lines not necessary to explain the drawing should be

erased before inking or broadening the pencil-lines, so as to make a minimum of erasing and cleaning after the drawing is finished.

When drawing pencil-lines, the pencil should be held in a plane passing through the edge of the T-square perpendicular to the plane of the paper and making an angle with the plane of the paper equal to about 60°.

Lines should always be drawn from left to right. A soft conical-pointed pencil should be used for lettering, figuring, and all free-hand work.

The Drawing-pen.—The best form, in the writer's opinion, is that shown in Fig. 14. The spring on the upper blade

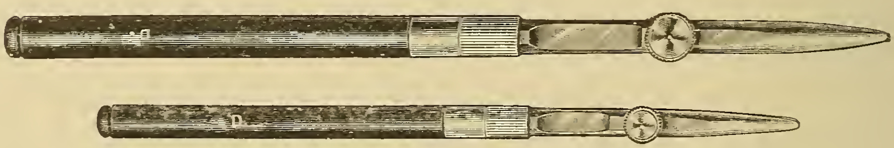


FIG. 14.

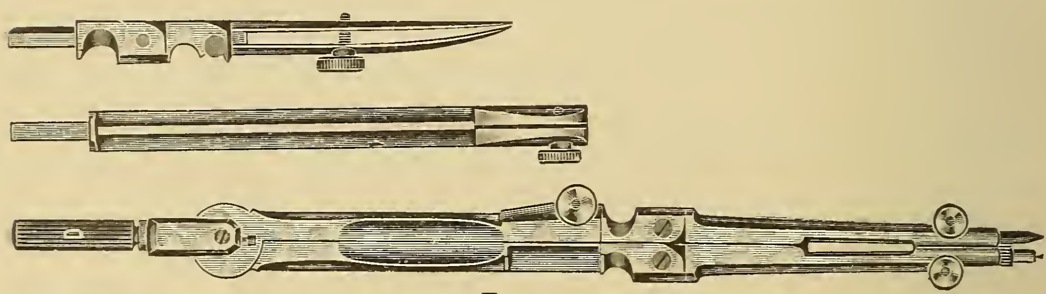


FIG. 15.

spreads the blades sufficiently apart to allow for thorough cleaning and sharpening. The hinged blade is therefore unnecessary. The pen should be held in a plane passing through the edge of the T-square at right angles to the plane of the paper, and making an angle with the plane of the paper ranging from 60° to 90°.

The best of drawing-pens will in time wear dull on the point, and until the student has learned from a competent teacher how to sharpen his pens it would be better to have them sharpened by the manufacturer.

It is difficult to explain the method of sharpening a drawing-pen.

If one blade has worn shorter than the other, the blades should be brought together by means of the thumb-screw, and placing the pen in an upright position draw the point to and fro on the oil-stone in a plane perpendicular to it, raising and lowering the handle of the pen at the same time, to give the proper curve to the point. The Arkansas oil-stones (No. 15 of "The Complete Outfit") are best for this purpose.

The blades should next be opened slightly, and holding the pen in the right hand in a nearly horizontal position, place the lower blade on the stone and move it quickly to and fro, slightly turning the pen with the fingers and elevating the handle a little at the end of each stroke. Having ground the lower blade a little, turn the pen completely over and grind the upper blade in a similar manner for about the same length of time; then clean the blades and examine the extreme points, and if there are still bright spots to be seen continue the grinding until they entirely disappear, and finish the sharpening by polishing on a piece of smooth leather.

The blades should not be too sharp, or they will cut the paper. The grinding should be continued only as long as the bright spots show on the points of the blades.

When inking, the pen should be held in about the same position as described for holding the pencil. Many draftsmen hold the pen vertically. The position may be varied

with good results as the pen wears. Lines made with the pen should only be drawn from left to right.

THE TRIANGLES.

The triangles shown at Fig. 4 (in "The Complete Outfit") are 10″ and 7″ long respectively, and are made of transparent celluloid. The black rubber triangles sometimes used are but very little cheaper (about 10 cents) and soon become dirty when in use; the rubber is brittle and more easily broken than the celluloid.

Angles of 15°, 75°, 30°, 45°, 60°, and 90° can readily be drawn with the triangles and T-square. Lines parallel to oblique lines on the drawing can be drawn with the triangles by placing the edge representing the height of one of them so as to coincide with the given line, then place the edge representing the hypotenuse of the other against the corresponding edge of the first, and by sliding the upper on the lower when holding the lower firmly with the left hand any number of lines may be drawn parallel to the given line.

The methods of drawing perpendicular lines and making angles with other lines within the scope of the triangles and T-square are so evident that further explanation is unnecessary.

THE T-SQUARE.

The use of the T-square is very simple, and is accomplished by holding the head firmly with the left hand against the left-hand end of the drawing-board, leaving the right hand free to use the pen or pencil in drawing the required lines.

THE DRAWING-BOARD.

If the left-hand edge of the drawing-board is straight and even and the paper is tacked down square with that edge and the T-square, then horizontal lines parallel to the upper edge of the paper and perpendicular to the left-hand edge may be drawn with the T-square, and lines perpendicular to these can be made by means of the triangles, or *set squares*, as they are sometimes called.

THE TRIANGULAR SCALE.

This scale, illustrated in Fig. 3 (in "The Complete Outfit"), was arranged to suit the needs of the students in machine drawing. It is triangular and made of boxwood. The six edges are graduated as follows; $\frac{1}{16}''$ or full size, $\frac{1}{50}''$, $\frac{3}{4}''$ and $\frac{3}{8}'' = 1$ ft., $1''$ and $\frac{1}{2}'' = 1$ ft., $3''$ and $1\frac{1}{2}'' = 1$ ft., and $4''$ and $2'' = 1$ ft.

Drawings of very small objects are generally shown enlarged—e.g., if it is determined to make a drawing twice the full size of an object, then where the object measures one inch the drawing would be made $2''$, etc.

Larger objects or small machine parts are often drawn full size—i.e., the same size as the object really is—and the drawing is said to be made to the scale of full size.

Large machines and large details are usually made to a reduced scale—e.g., if a drawing is to be made to the scale of $2'' = 1$ ft., then $2''$ measured by the standard rule would be divided into 12 equal parts and each part would represent $1''$. See Fig. 81*b*.

THE SCALE GUARD.

This instrument is shown in No. 17 (in "The Complete Outfit"). It is employed to prevent the scale from turning, so that the draftsman can use it without having to look for the particular edge he needs every time he wants to lay off a measurement.

THE COMPASSES.

When about to draw a circle or an arc of a circle, take hold of the compass at the joint with the thumb and two first fingers, guide the needle-point into the center and set the pencil or pen leg to the required radius, then move the thumb and forefinger up to the small handle provided at the top of the instrument, and beginning at the lowest point draw the line clockwise. The weight of the compass will be the only down pressure required.

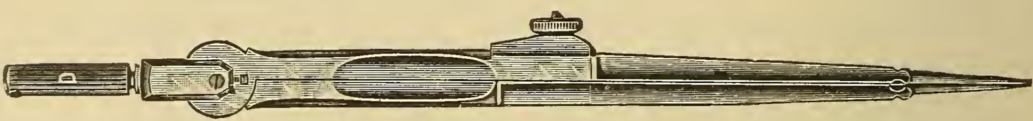


FIG. 16.

The sharpening of the lead for the compasses is a very important matter, and cannot be emphasized too much. Before commencing a drawing it pays well to take time to properly sharpen the pencil and the lead for compasses and to keep them always in good condition.

The directions for sharpening the compass leads are the same as has already been given for the sharpening of the straight-line pencil.

THE DIVIDERS OR SPACERS.

This instrument should be held in the same manner as described for the compass. It is very useful in laying off equal distances on straight lines or circles. To divide a given line into any number of equal parts with the dividers, say 12, it is best to divide the line into three or four parts first, say 4, and then when one of these parts has been subdivided accurately into three equal parts, it will be a simple matter to step off these latter divisions on the remaining three-fourths

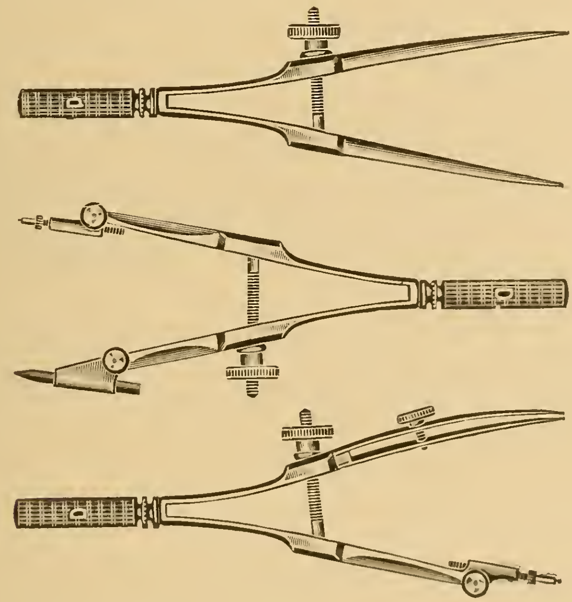


FIG. 17.

of the given line. Care should be taken not to make holes in the paper with the spacers, as it is difficult to ink over them without blotting.

THE SPRING BOWS.

These instruments are valuable for drawing the small circles and arcs of circles. It is very important that all the

small arcs, such as fillets, round corners, etc., should be carefully pencilled in before beginning to ink a drawing. Many good drawings are spoiled because of the bad joints between small arcs and straight lines.

When commencing to ink a drawing, all small arcs and small circles should be inked first, then the larger arcs and circles, and the straight lines last. This is best, because it is much easier to know where to stop the arc line, and to draw the straight line tangent to it, than *vice versa*.

IRREGULAR CURVES.

The irregular curve shown in Fig. 5 is useful for drawing irregular curves through points that have already been found by construction, such as ellipses, cycloids epicyloids, etc., as in the cases of gear-teeth, cam outlines, rotary pump wheels, etc.

When using these curves, that curve should be selected that will coincide with the greatest number of points on the line required.

THE PROTRACTOR.

This instrument is for measuring and constructing angles. It is shown in Fig. 12. It is used as follows when measuring an angle: Place the lower straight edge on the straight line which forms one of the sides of the angle, with the nick exactly on the point of the angle to be measured. Then the number of degrees contained in the angle may be read from the left, clockwise.

In constructing an angle, place the nick at the point from which it is desired to draw the angle, and on the outer circum-

ference of the protractor, find the figure corresponding to the number of degrees in the required angle, and mark a point on the paper as close as possible to the figure on the protractor; after removing the protractor, draw a line through this point to the nick, which will give the required angle.

CHAPTER II.

GEOMETRICAL DRAWING.

The following problems are given to serve a double purpose: to teach the use of drawing instruments, and to point out those problems in practical geometry that are most useful in mechanical drawing, and to impress them upon the mind of the student so that he may readily apply them in practice.

The drawing-paper for this work should be divided temporarily, with light pencil-lines, into as many squares and rectangles as may be directed by the instructor, and the drawings made as large as the size of the squares will permit. The average size of the squares should be not less than 4″. When a sheet of drawings is finished these boundary lines may be erased.

It will be noticed in the illustrations of this chapter that all construction lines are made very narrow, and given and required lines quite broad. This is sufficient to distinguish them, and employs less time than would be necessary if the construction lines were made broken, as is often the case.

If time will permit, it is advisable to ink in some of these drawings toward the last. In that event, the given lines may be red, the construction lines blue, and the required lines black.

But even when inked in in black, the broad and narrow

lines would serve the purpose very well without the use of colored inks.

The principal thing to be aimed at in making these drawings is accuracy of construction. All dimensions should be laid off carefully, correctly, and quickly. Straight lines joining arcs should be exactly tangent, so that the joints cannot be noticed. It is the little things like these that make or mar a drawing, and if attended to or neglected they will make or mar the draftsman. The constant endeavor of the student should be to make every drawing he begins more accurate, quicker and better in every way than the preceding one.

A drawing should never be handed in as finished until the student is perfectly sure that he cannot improve it in any way whatever, for the act of handing in a drawing is the same, or should be the same, as saying This is the best that I can do; I cannot improve it; it is a true measure of my ability to make this drawing.

If these suggestions are faithfully followed throughout this course, success awaits *any one* who earnestly desires it.

Prob. 1. Fig. 18. TO BISECT A FINITE STRAIGHT LINE.—With A and B in turn as centers, and a radius greater than the half of AB, draw arcs intersecting at E and F. Join EF bisecting AB at C.

An arc of a circle may be bisected in the same way.

Prob. 2. Fig. 19. TO ERECT A PERPENDICULAR AT THE END OF THE LINE.—Assume the point E above the line as center and radius EB describe an arc CBD cutting the line AB in the point C. From C draw a line through E cutting the arc in D. Draw DB the perpendicular.

Prob. 3. Fig. 20. THE SAME PROBLEM: A SECOND METHOD.—

With center *B* and any radius as *BC* describe an arc *CDE* with the same radius; measure off the arcs *CD* and *DE*. With *D* and *E* as centers and any convenient radius describe arcs intersecting at *F*. *FB* is the required perpendicular.

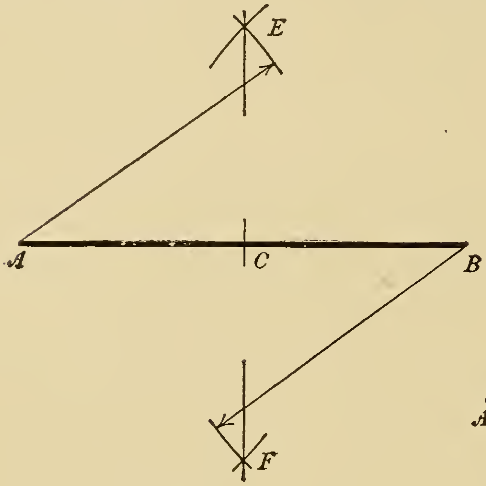


FIG. 18.

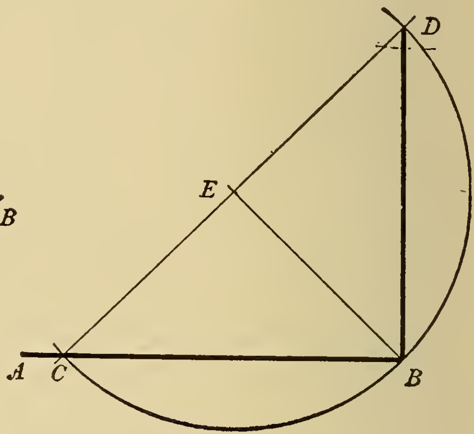


FIG. 19.

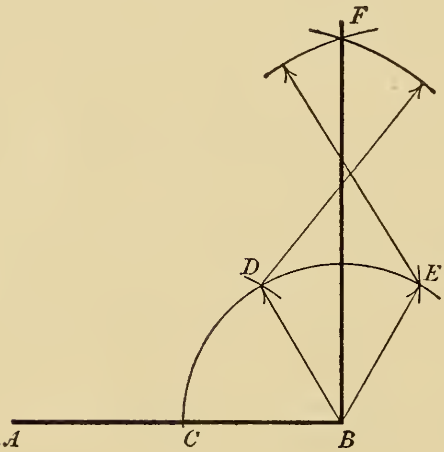


FIG. 20.

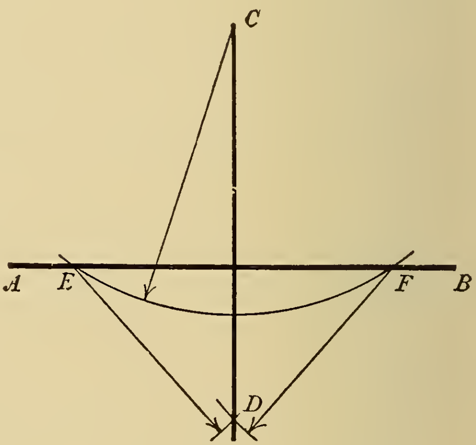


FIG. 21.

Prob. 4. Fig. 21. TO DRAW A PERPENDICULAR TO A LINE FROM A POINT ABOVE OR BELOW IT.—Assume the point *C* above the line. With center *C* and any suitable radius cut the line *AB* in *E* and *F*. From *E* and *F* describe arcs cutting in *D*. Draw *CD* the perpendicular required.

Prob. 5. Fig. 22. TO BISECT A GIVEN ANGLE.—With A as center and any convenient radius describe the arc BC. With B and C as centers and any convenient radius draw arcs intersecting at D. Join AD, then angle $BAD =$ angle DAC.

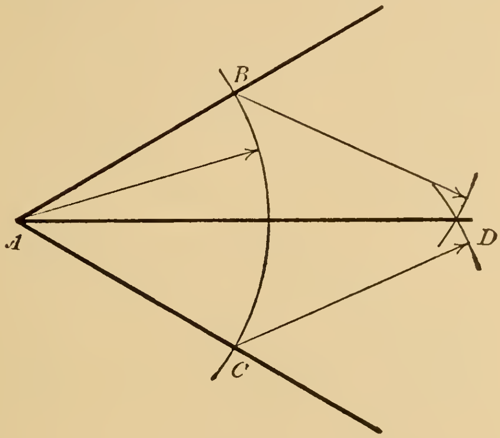


FIG. 22.

Prob. 6. Fig. 23. TO DRAW A LINE PARALLEL TO A GIVEN LINE AB THROUGH A GIVEN POINT C.—From any point on AB as B with radius BC describe an arc cutting AB in A. From C with the same radius describe arc BD. From B with AC as radius cut arc BD in D. Draw CD. Line CD is parallel to AB.

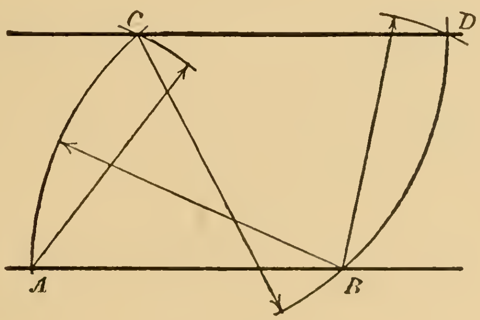


FIG. 23.

Prob. 7. Fig. 24. FROM A POINT D ON THE LINE DE TO SET OFF AN ANGLE EQUAL TO THE GIVEN ANGLE BAC.—From

A with any convenient radius describe arc *BC*. From *D* with the same radius describe arc *EF*. With center *E* and radius *BC* cut arc *EF* in *F*. Join *DF*. Angle *EDF* is = angle *BAC*.

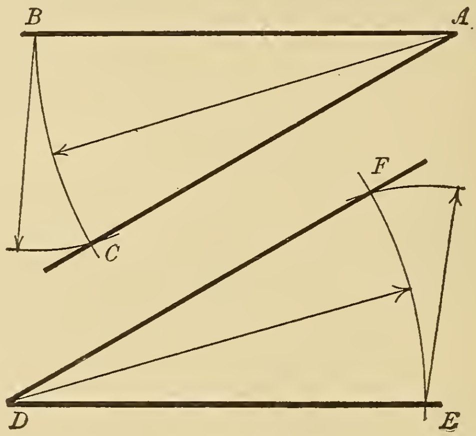


FIG. 24.

Prob. 8. Fig. 25. TO DIVIDE AN ANGLE INTO TWO EQUAL PARTS, WHEN THE LINES DO NOT EXTEND TO A MEETING POINT.—Draw the line *CD* and *CE* parallel and at equal distances from the lines *AB* and *FG*. With *C* as center and any radius draw arcs 1, 2. With 1 and 2 as centers and any con-

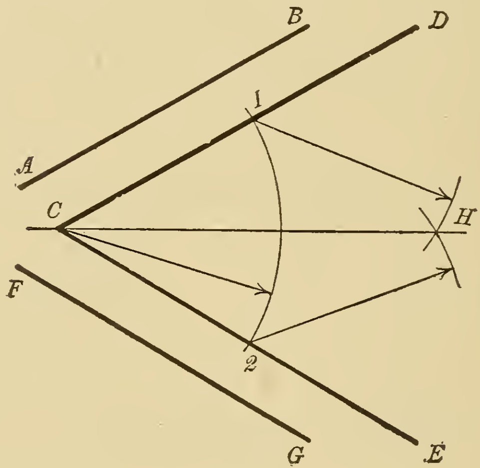


FIG. 25.

venient radius describe arcs intersecting at *H*. A line through *C* and *H* divides the angle into two equal parts.

Prob. 9. Fig. 26. TO CONSTRUCT A RHOMBOID HAVING ADJACENT SIDES EQUAL TO TWO GIVEN LINES *AB* AND *AC*, AND AN ANGLE EQUAL TO A GIVEN ANGLE *A*.—Draw line *DE* equal to *AB*. Make $D =$ angle *A*. Make $DF = AC$. From *F* with line *AB* as radius and from *E* with line *AC* as radius describe arcs cutting in *G*. Join *FG* and *EG*.

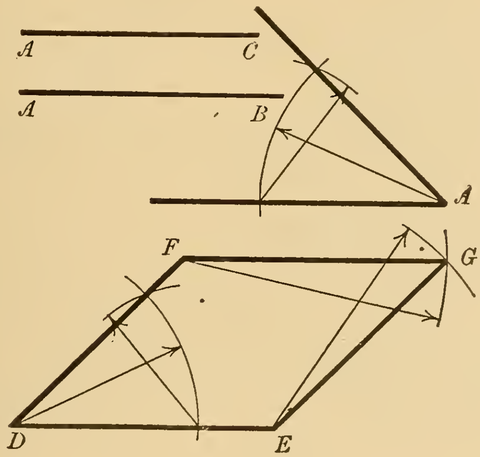


FIG. 26

Prob. 10. Fig. 27. TO DIVIDE THE LINE *AB* INTO ANY NUMBER OF EQUAL PARTS, SAY 15.—Draw a line *CD* parallel to *AB*, of any convenient length. From *C* set off along this line the number of equal parts into which the line *AB* is to be divided. Draw *CA* and *DB* and produce them until they intersect at *E*. Through each one of the points 1, 2, 3, 4, etc., draw lines to the point *E*, dividing the line *AB* into the required number of equal parts.

This problem is useful in dividing a line when the point required is difficult to find accurately—e.g., in Fig. 28 *AB* is the *pitch* of the spur gear, partly shown, which includes a

space and a tooth and is measured on the *pitch circle.* In cast gears the space is made larger than the thickness of the tooth, the proportion being about 6 to 5—i.e., if we divide the pitch into eleven equal parts the space will measure $\frac{6}{11}$

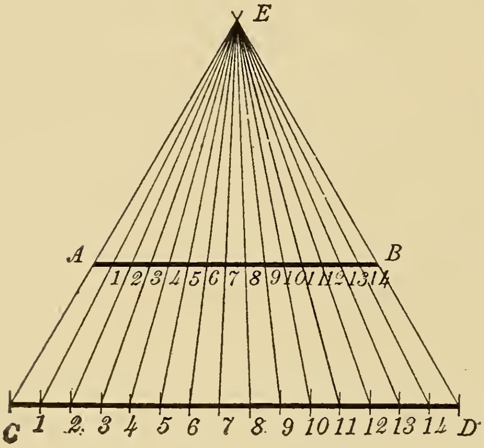


FIG. 27.

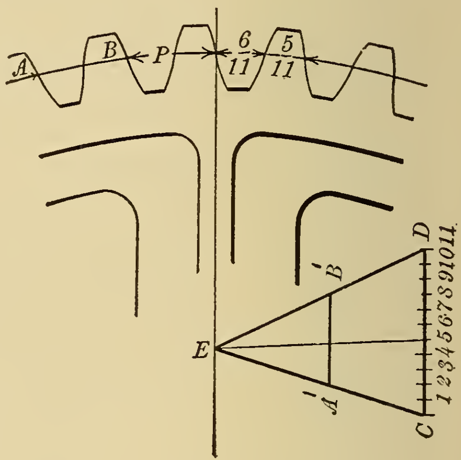


FIG 28.

and the tooth $\frac{5}{11}$. The $\frac{1}{11}$ which the space is larger than the tooth is called the *backlash.* Let $A'B'$ be the pitch chord of the arc AB. Draw CD parallel to $A'B'$ at any convenient distance and set off on it 11 equal spaces of any convenient length. Draw CA' and DB' intersecting at E. From point 5 draw a line to E which will divide $A'B'$ as required; the one part $\frac{5}{11}$ and the other $\frac{6}{11}$.

Prob. 11. Fig. 29. TO DIVIDE A GIVEN LINE INTO ANY NUMBER OF EQUAL PARTS: ANOTHER METHOD.—Let AB be the given line. From A draw AC at any angle, and lay off on it the required number of equal spaces of any convenient length. Join CB and through the divisions on AC draw lines parallel to CB, dividing AB as required in the points 1′, 2′, 3′, 4′, etc.

Prob. 12. Fig. 30. TO DIVIDE A LINE AB PROPORTIONALLY TO THE DIVIDED LINE CD.—Draw AB parallel to CD at any

distance from it. Draw lines through *CA* and *DB* and produce them till they meet at *E*. Draw lines from *E* through the divisions 1, 2, 3, 4, etc., of line *CD*, cutting line *AB* in the

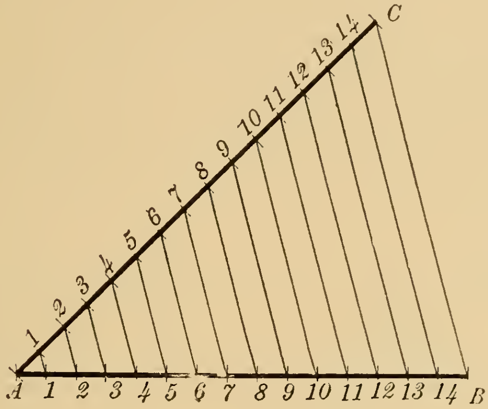


FIG. 29.

points 5, 6, 7, 8, etc. The divisions on *AB* will have the same proportion to the divisions on *CD* that the whole line *AB* has to the whole line *CD*—i.e., the lines will be proportionally divided.

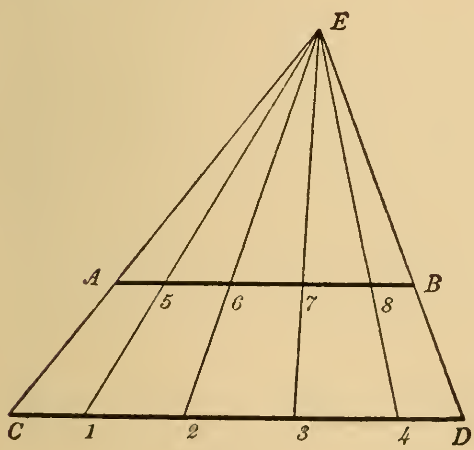


FIG. 30.

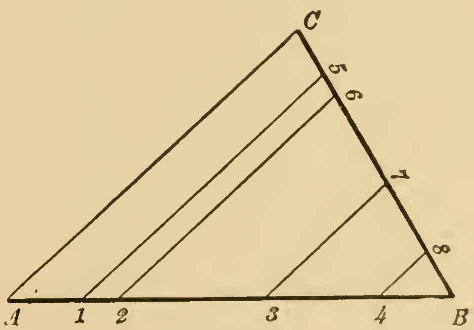


FIG. 31.

Prob. 13. Fig. 31. THE SAME: ANOTHER METHOD.—Let *BC*, the divided line, make any angle with *BA*, the line to be di-

vided at *B*. Draw line *CA* joining the two ends of the lines. Draw lines from 5, 6, 7, 8, parallel to *CA*, dividing line *AB* in points 1, 2, 3, 4, proportional to *BC*.

Prob. 14. Fig. 32. TO CONSTRUCT AN EQUILATERAL TRIANGLE ON A GIVEN BASE *AB*.—From the points *A* and *B* with *AB* as radius describe arcs cutting in *C*. Draw lines *AC* and *BC*. The triangle *ABC* is equilateral and equiangular.

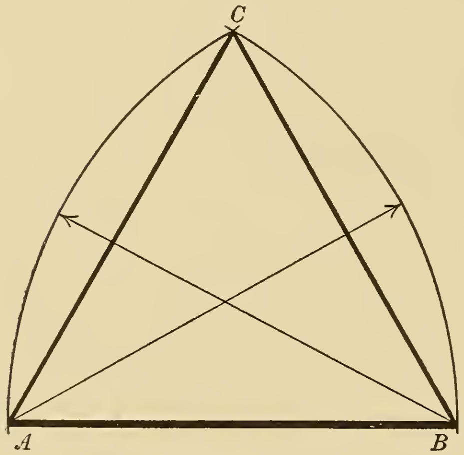


FIG. 32

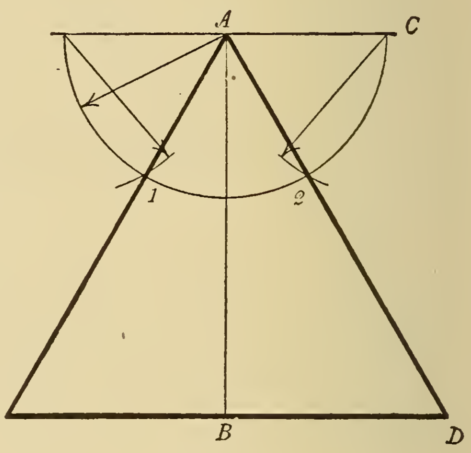


FIG. 33.

Prob. 15. Fig. 33. TO CONSTRUCT AN EQUILATERAL TRIANGLE OF A GIVEN ALTITUDE, *AB*.—From both ends of *AB* draw lines perpendicular to it as *CA* and *DB*. From *A* with any radius describe a semicircle on *CA* and with its radius cut off arcs 1, 2. Draw lines from *A* through 1, 2, and produce them until they cut the base *BD*.

Prob. 16. Fig. 34. TO TRISECT A RIGHT ANGLE *ABC*.— From the angular point *B* with any convenient radius describe an arc cutting the sides of the angle in *C* and *A*. From *C* and *A* with the same radius cut off arcs 1 and 2. Draw lines 1*B* and 2*B*, and the right angle will be trisected.

Prob. 17. Fig. 35. TO CONSTRUCT ANY TRIANGLE, ITS THREE SIDES *AB* AND *C* BEING GIVEN.—From one end of the base as *A* describe an arc with the line *B* as radius. From the other end with line *C* as radius describe an arc, cutting the first arc in *D*. From *D* draw lines to the ends of line *A*, and a triangle will be constructed having its sides equal to the sides given. To construct any triangle the two shorter sides *B* and *C* must together be more than equal to the largest side *A*.

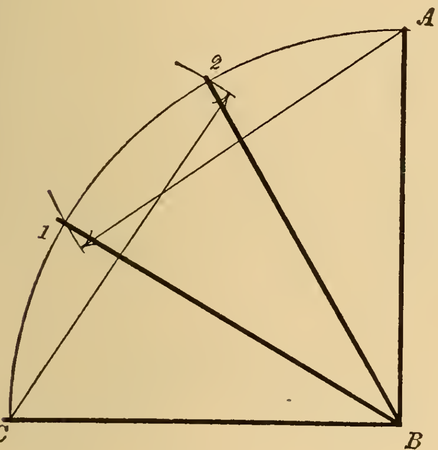


FIG. 34.

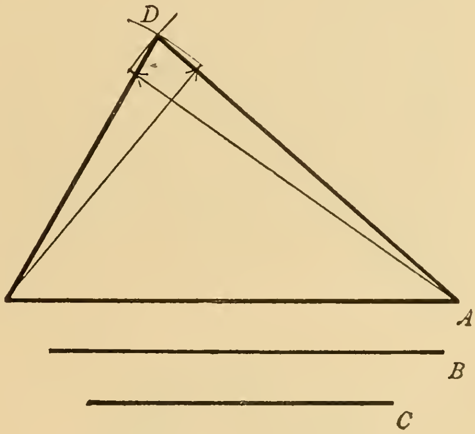


FIG. 35.

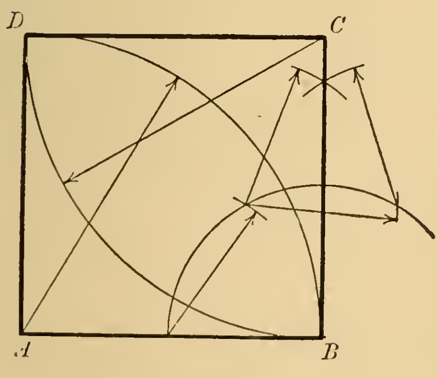


FIG. 36.

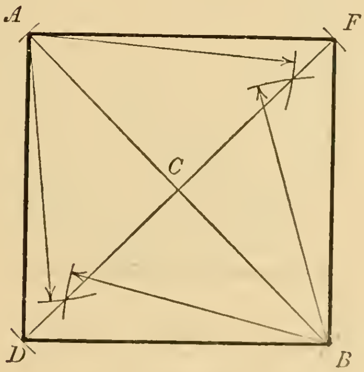


FIG. 37.

Prob. 18. Fig. 36. TO CONSTRUCT A SQUARE, ITS BASE *AB* BEING GIVEN.—Erect a perpendicular at *B*. Make *BC* equal

to *AB*. From *A* and *C* with radius *AB* describe arcs cutting in *D*. Join *DC* and *DA*.

Prob. 19. Fig. 37. To Construct a Square, given its Diagonal *AB*.—Bisect *AB* in *C*. Draw *DF* perpendicular to *AB* at *C*. Make *CD* and *CF* each equal to *CA*. Join *AD*, *DB*, *BF*, and *FA*.

Prob. 20. Fig. 38. To Construct a Regular Polygon of any Number of Sides, the Circumscribing Circle being given.—At any point of contact, as *C*, draw a tangent *AB* to the given circle. From *C* with any radius describe a semicircle cutting the given circle. Divide the semicircle into as many equal parts as the polygon is required to have sides, as 1, 2, 3, 4, 5, 6. Draw lines from *C* through each division, cutting the circle in points which will give the angles of the polygon.

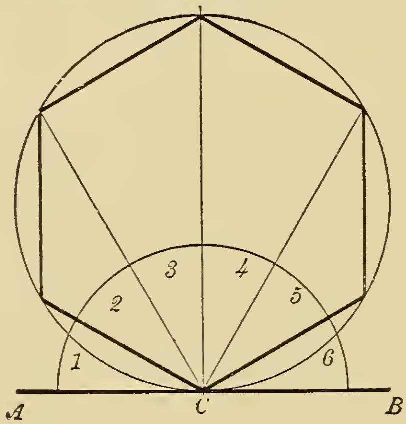


Fig. 38.

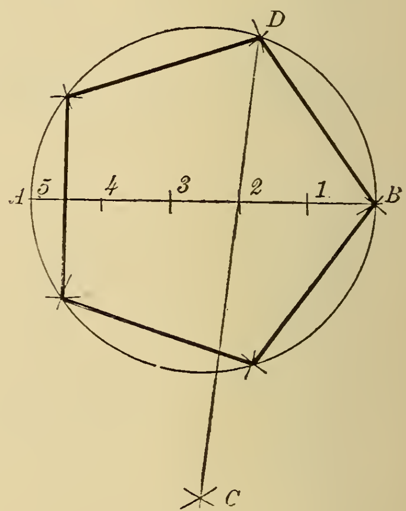


Fig. 39.

Prob. 21. Fig. 39. Another Method.—Draw a diameter *AB* of the given circle. Divide *AB* into as many equal parts as the polygon is to have sides, say 5. From *A* and *B* with the

line *AB* as radius describe arcs cutting in *C*, draw a line from *C* through the second division of the diameter and produce it cutting the circle in *D*. *BD* will be the side of the required polygon. The line *C* must always be drawn through the second division of the diameter, whatever the number of sides of the polygon.

Prob. 22. Fig. 40. TO CONSTRUCT ANY REGULAR POLYGON WITH A GIVEN SIDE *AB*.—Make *BD* perpendicular and equal to *AB*. With *B* as center and radius *AB* describe arc *DA*. Divide arc *DA* into as many equal parts as there are sides in the required polygon, as 1, 2, 3, 4, 5. Draw *B*2. Bisect line *AB* and erect a perpendicular at the bisection cutting *B*2 in *C*. With *C* as center and radius *CB* describe a circle. With *AB* as a chord step off the remaining sides of the polygon.

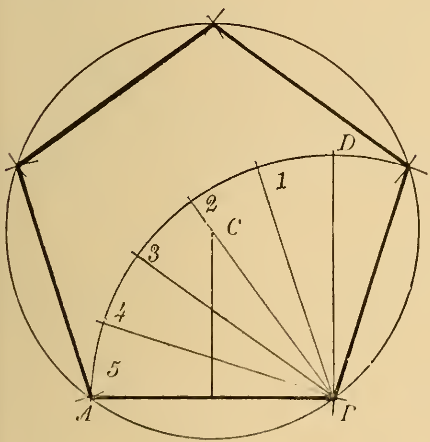


FIG. 40.

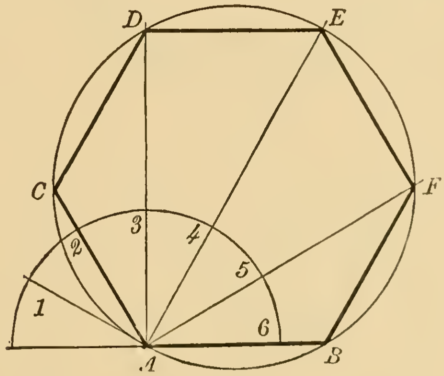


FIG. 41.

Prob. 23. Fig. 41. ANOTHER METHOD.—Extend line *AB*. With center *A* and any convenient radius describe a semicircle. Divide the semicircle into as many equal parts as there are sides in the required polygon, say 6. Draw lines through every division except the first. With *A* as center and *AB* as

radius cut off $A2$ in C. From C with the same radius cut $A3$ in D. From D, $A4$ in E. From B, $A5$ in F. Join AC, CD, DE, EF, and FB.

Prob. 24. Fig. 42. To Construct a Regular Heptagon, the Circumscribing Circle being given.—Draw a radius AB. With B as center and BA as radius, cut the circumference in 1, 2; it will be bisected by the radius in C. $C1$ or $C2$ is equal to the side of the required heptagon.

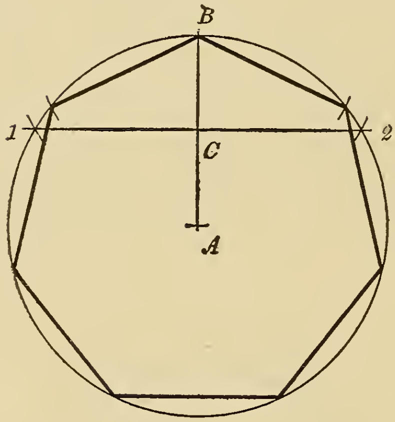


Fig. 42.

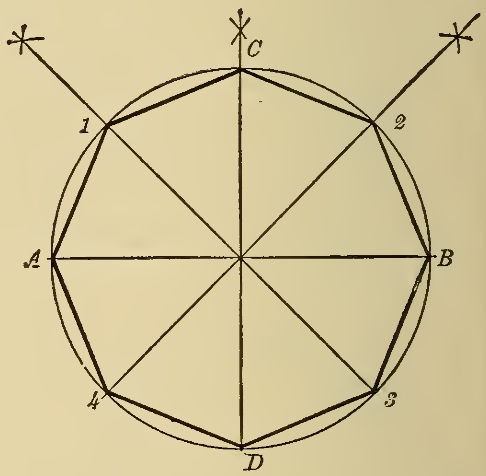


Fig 43.

Prob. 25. Fig. 43. To Construct a Regular Octagon, the Circumscribing Circle being given.—Draw a diameter AB. Bisect the arcs AB in C and D. Bisect arcs CA and CB in 1 and 2. Draw lines from 1 and 2 through the center of the circle, cutting the circumference in 3 and 4. Join $A1$, $1C$, $C2$, $2B$, $B3$, etc.

Prob. 26. Fig. 44. To Construct a Pentagon, the Side AB being given.—Produce AB. With B as center and BA as radius, describe arc $AD2$. With center A and same radius, describe an arc cutting the first arc in D. Bisect AB in E.

Draw line *DE*. Bisect arc *BD* in *F*. Draw line *EF*. With center *C* and radius *EF* cut off arc *C*1 and 1, 2 on the semicircle. Draw line *B*2; it will be a second side of the penta-

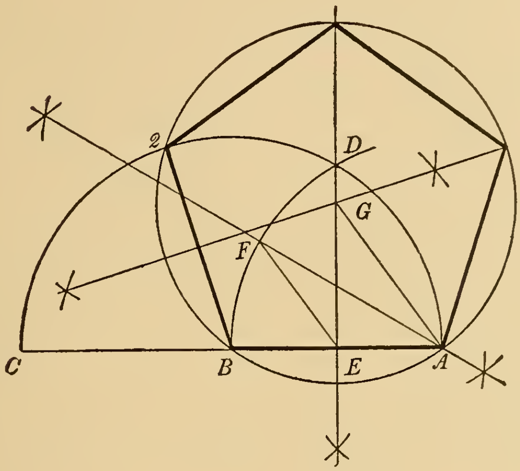


FIG. 44.

gon. Bisect it and draw a line perpendicular to it at the bisection. The perpendiculars from the sides *AB* and *B*2 will cut in *G*. With *G* as center and radius *GA* describe a circle· it will contain the pentagon.

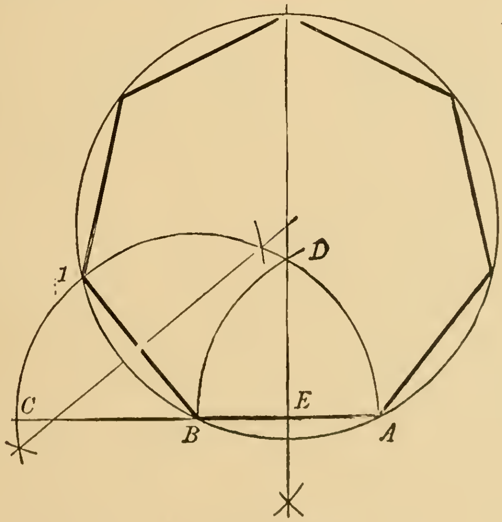


FIG. 45.

Prob. 27. Fig. 45. TO CONSTRUCT A HEPTAGON ON A GIVEN LINE *AB*.—Extend line *AB* to *C*. From *B* with radius *AB* describe a semicircle. With center *A* and same radius describe an arc cutting the semicircle in *D*. Bisect *AB* in *E*. Draw line *DE*. With *C* as center and *DE* as radius, cut off arc 1 on the semicircle. Draw line *B*1; it is a second side of the heptagon. Bisect it and obtain the center of the circumscribing circle as in the preceding problem.

Prob. 28. Fig. 46. TO INSCRIBE AN OCTAGON IN A GIVEN SQUARE.—Draw diagonals *AD*, *CB* intersecting at *O*. From *A*, *B*, *C*, and *D* with radius equal to *AO* describe quadrants cutting the sides of the square in 1, 2, 3, 4, 5, 6, 7, 8. Join these points and the octagon will be inscribed.

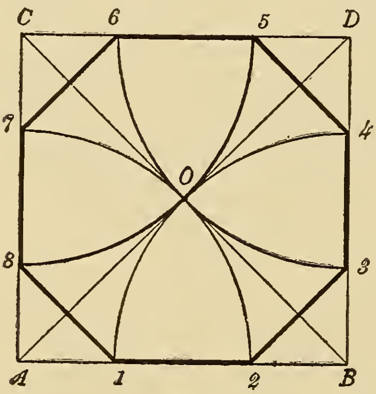


FIG. 46.

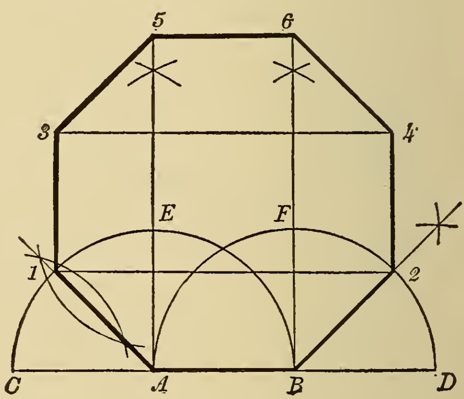


FIG. 47.

Prob. 29. Fig. 47. TO CONSTRUCT A REGULAR OCTAGON ON A GIVEN LINE *AB*.—Extend line *AB* in both directions. Erect perpendiculars at *A* and *B*. With centers *A* and *B* and radius *AB* describe the semicircle *CEB* and *AF*2. Bisect the quadrants *CE* and *DF* in 1 and 2, then *A*1 and *B*2 will be two more sides of the octagon. At 1 and 2 erect perpendiculars 1, 3 and 2, 4 equal to *AB*. Draw 1–2 and 3–4. Make the

perpendiculars at *A* and *B* equal to 1–2 or 3–4—viz., *A*5 and *B*6. Complete the octagon by drawing 3–5, 5–6, and 6–4.

Prob. 30. Fig. 48. TO DRAW A RIGHT LINE EQUAL TO HALF THE CIRCUMFERENCE OF A GIVEN CIRCLE.—Draw a diameter *AB*. Draw line *AC* perpendicular to *AB* and equal to three times the radius of the circle. Draw another perpendicular at *B* to *AB*. With center *B* and radius of the circle cut off arc *BD*, bisect it and draw a line from the center of the circle through the bisection, cutting line *B* in *E*. Join *EC*. Line *EC* will be equal to half the circumference of circle *A*.

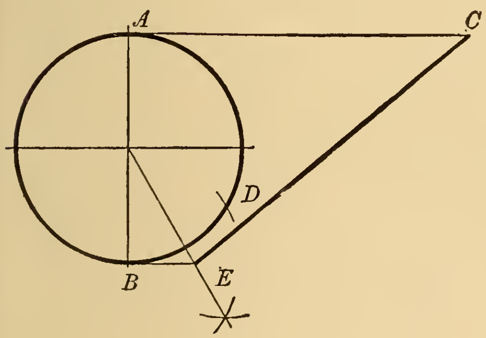


FIG. 48.

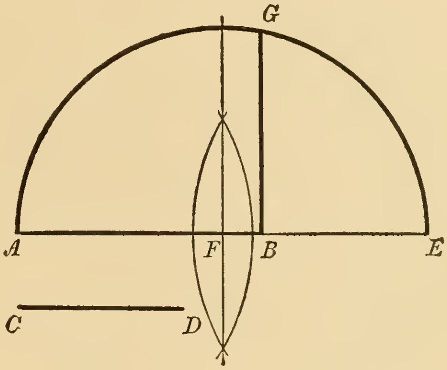


FIG. 49.

Prob. 31. Fig. 49. TO FIND A MEAN PROPORTIONAL TO TWO GIVEN RIGHT LINES.—Extend the line *AB* to *E* making *BE* equal to *CD*. Bisect *AE* in *F*. From *F* with radius *FA* describe a semicircle. At *B* where the two given lines are joined erect a perpendicular to *AE* cutting the semicircle in *G*. *BG* will be a mean proportional to *CD* and *AB*.

Prob. 32. Fig. 50. TO FIND A THIRD PROPORTIONAL (LESS) TO TWO GIVEN RIGHT LINES *AB* AND *CD*.—Make *EF* = the given line *AB*. Draw *EG* = *DC* making an angle with *EF*. Join *FG*. From *E* with *EG* as radius cut *EF* in *H*. Draw

H parallel to *FG*, cutting *EG* in *I*. *EI* is the third proportional (less) to the two given lines.

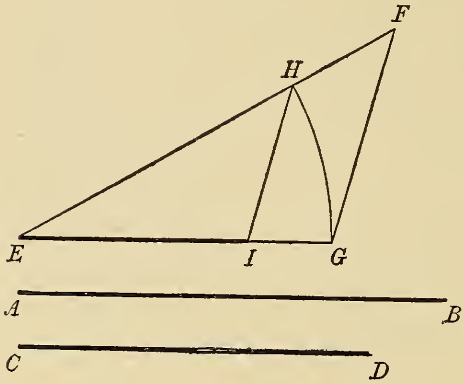


FIG. 50.

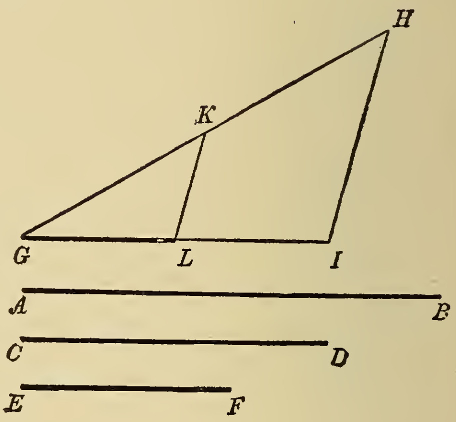


FIG. 51.

Prob. 33. Fig. 51. TO FIND A FOURTH PROPORTIONAL TO THREE GIVEN RIGHT LINES *AB*, *CD*, AND *EF*.—Make *GH* = the given line *AB*. Draw *GI* = *CD*, making any convenient angle to *GH*. Join *HI*. From *G* lay off *GK* = *EF*. From *K* draw a parallel to *HI* cutting *GI* in *L*. *GL* is the fourth proportional required.

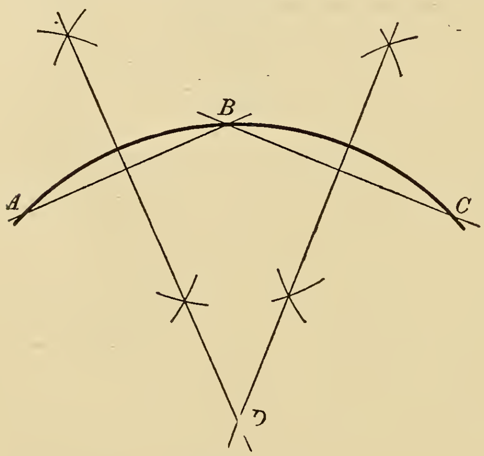


FIG. 52.

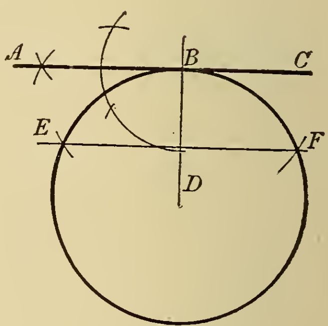


FIG. 53.

Prob. 34. Fig. 52. TO FIND THE CENTER OF A GIVEN ARC *ABC*. —Draw the chords *AB* and *CD* and bisect them. Extend the bisection lines to intersect in *D* the center required.

Prob. 35. Fig. 53. TO DRAW A LINE TANGENT TO AN ARC OF A CIRCLE.—(1st.) When the center is not accessible. Let *B* be the point through which the tangent is to be drawn. From *B* lay off equal distances as *BE*, *BF*. Join *EF* and through *B* draw *ABC* parallel to *EF*. (2d.) When the center *D* is given. Draw *BD* and through *B* draw *ABC* perpendicular to *BD*. *ABC* is tangent to the circle at the point *B*.

Prob. 36. Fig. 54. TO DRAW TANGENTS TO THE CIRCLE *C* FROM THE POINT *A* WITHOUT IT.—Draw *AC* and bisect it in *E*. From *E* with radius *EC* describe an arc cutting circle *C* in *B* and *D*. Join *CB*, *CD*. Draw *AB* and *AD* tangent to the circle *C*.

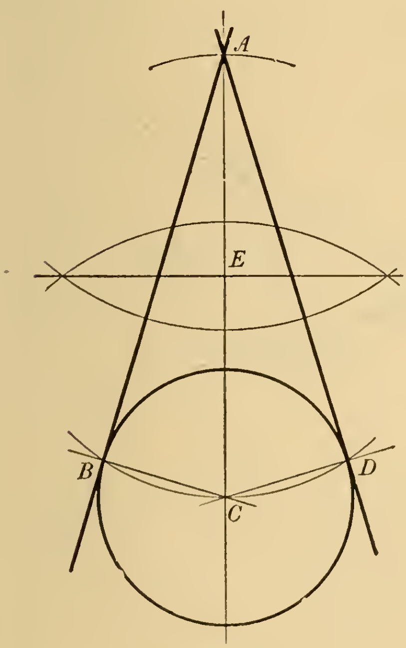


FIG. 54.

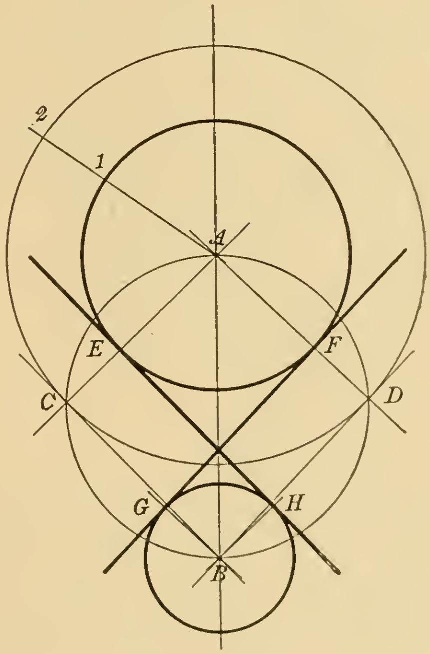


FIG. 55.

Prob. 37. Fig. 55. TO DRAW A TANGENT BETWEEN TWO CIRCLES.—Join the centers *A* and *B*. Draw any radial line from *A* as *A*2 and make 1–2 = the radius of circle *B*. From *A* with radius *A*–2 describe a circle *C*2*D*. From center *B*

draw tangents *BC* and *BD* to circle *C2D* at the points *C* and *D* by preceding problem. Join *AC* and *AD* and through the points *E* and *F* draw parallels *FG* and *EH* to *BD* and *BC*. *FG* and *EH* are the tangents required.

Prob. 38. Fig. 56. TO DRAW TANGENTS TO TWO GIVEN CIRCLES *A* AND *B*.—Join *A* and *B*. From *A* with a radius equal to the difference of the radii of the given circles de-

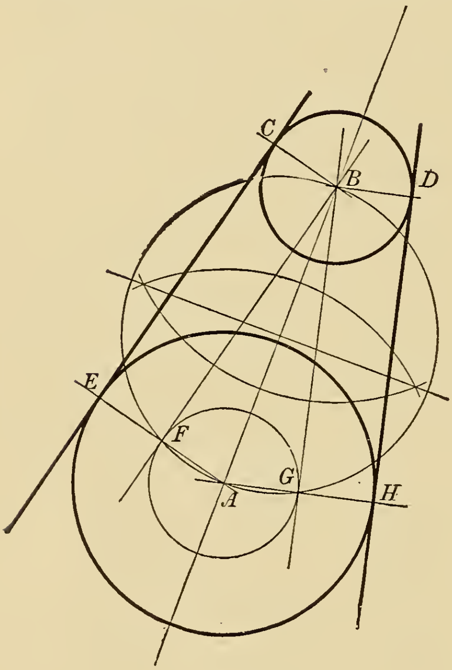


FIG. 56.

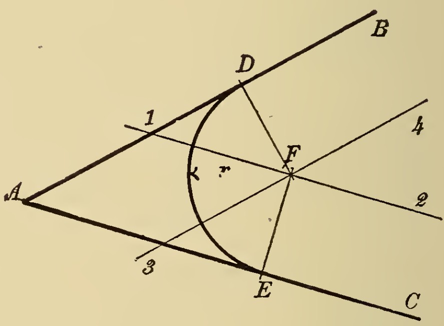


FIG. 57.

scribe a circle *GF*. From *B* draw the tangents *BF* and *BG*, by Prob. 37. Draw *AF* and *AG* extended to *E* and *H*. Through *E* and *H* draw *EC* and *HD* parallel to *BF* and *BG* respectively. *EC* and *DH* are the tangents required.

Prob. 39. Fig. 57. TO DRAW AN ARC OF A CIRCLE OF GIVEN RADIUS TANGENT TO TWO STRAIGHT LINES.—*AB* and *AC* are the two straight lines, and *r* the given radius. At a distance = *r* draw parallels 1–2 and 3–4 to *AC* and *AB*, inter-

secting at F. From F draw perpendiculars FD and FE. With F as center and FD or FE as radius describe the required arc, which will be tangent to the two straight lines at the points D and E.

Prob. 40. Fig. 58. To Draw an Arc of a Circle Tangent to two Straight Lines BC and CD when the Mid-position G is given.—Draw CA the bisection of the angle BCD and EF at right angles to it through the given point G. Next bisect either of the angles FEB or EFD. The bisection line will intersect the central line CA at A, which will be the center of the arc. From A draw perpendiculars A1 and A2, and with either as a radius and A as center describe an arc which will be tangent to the lines BC and CD at the points 1 and 2.

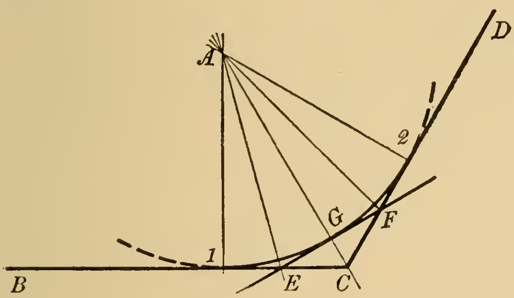


Fig. 58.

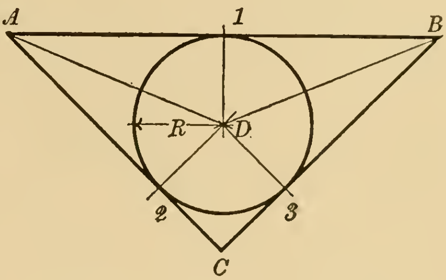


Fig. 59.

Prob. 41. Fig. 59. To Inscribe a Circle within a Triangle ABC.—Bisect the angles A and B. The bisectors will meet in D. Draw D1 perpendicular to AB. Then with center D and radius $= D$1 describe a circle which will be tangent to the given triangle at the points 1, 2, 3.

Prob. 42. Fig. 60. To Draw an Arc of a Circle of Given Radius R tangent to two Given Circles A and B.—From A and B draw any radial lines as A3, B4. Outside the circumference of each circle cut off distances 1–3 and 2–4

each = the given radius *R*. Then with center *A* and radius *A*–3, and center *B* and radius *B*–4 describe arcs intersecting at *C*. Draw *CA*, *CB* cutting the circles at 5 and 6. With centre *C* and radius *C*5 or *C*6 describe an arc which will be tangent at points 5 and 6.

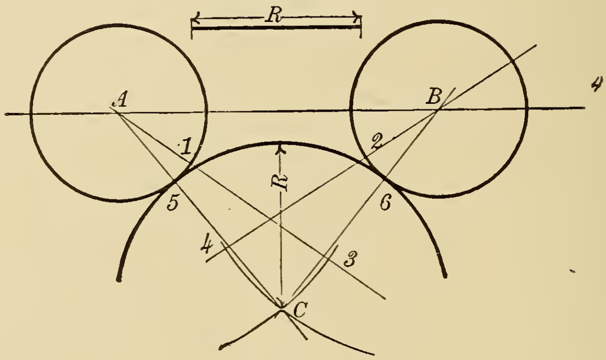


FIG. 60.

Prob. 43. Fig. 61. TO DRAW AN ARC OF A CIRCLE OF GIVEN RADIUS *R* TANGENT TO TWO GIVEN CIRCLES *A* AND *B*

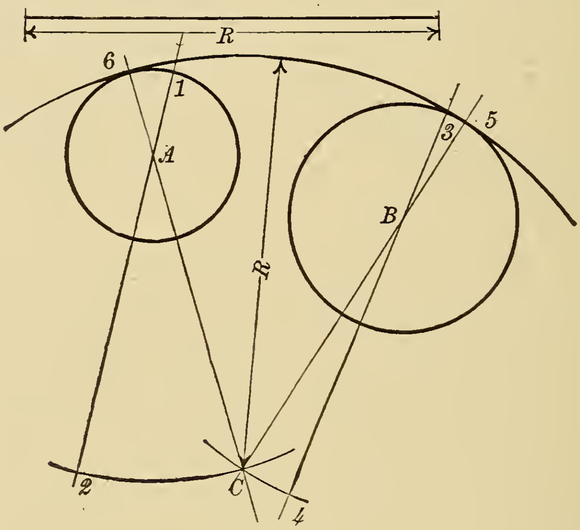


FIG 61.

WHEN THE ARC INCLUDES THE CIRCLES.—Through *A* and *B* draw convenient diameters and extend them indefinitely. On

these measure off the distances 1–2 and 3–4, each equal in length to the given radius *R*. Then with center *A* and radius *A*2, center *B* and radius *B*4, describe arcs cutting at *C*. From *C* draw *C*5 and *C*6 through *B* and *A*. With center *C* and radius *C*6 or *C*5 describe the arc 6, 5, which will be tangent to the circles at the points 6 and 5.

Prob. 44. Fig. 62. To Draw an Arc of a Circle of Given Radius *R* tangent to Two Given Circles *A* and *B* when the Arc includes one Circle and excludes the other.—Through *A* draw any diameter and make 1–2 = *R*.

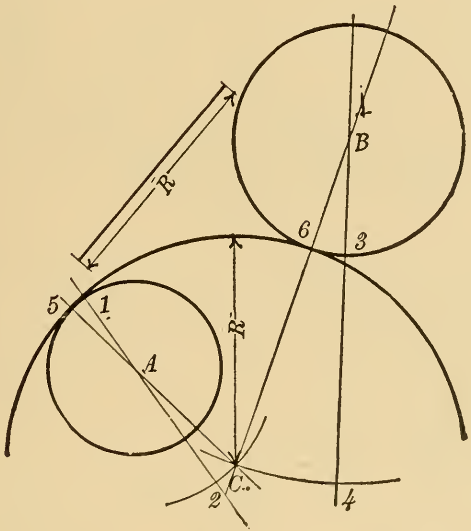


Fig. 62.

From *B* draw any radius and extend it, making 3–4 = *R*. With center *A* and radius *A*2 and center *B* and radius *B*4 describe arcs cutting at *C*. With *C* as center and radius = *C*5 or *C*6 describe the arc 5, 6.

Prob. 45. Fig. 63. Draw an Arc of a Circle of Given Radius *R* tangent to a Straight Line *AB* and a Circle *CD*.—From *E*, the center of the given circle, draw an arc of a

circle 1, 2 concentric with *CD* at a distance *R* from it, and also a straight line 3, 4 parallel to *AB* at the same distance *R* from *AB*. Draw *EO* intersecting *CD* at 5. Draw the perpendicular *O*6. With center *O* and radius *O*6 or *O*5 describe the required arc.

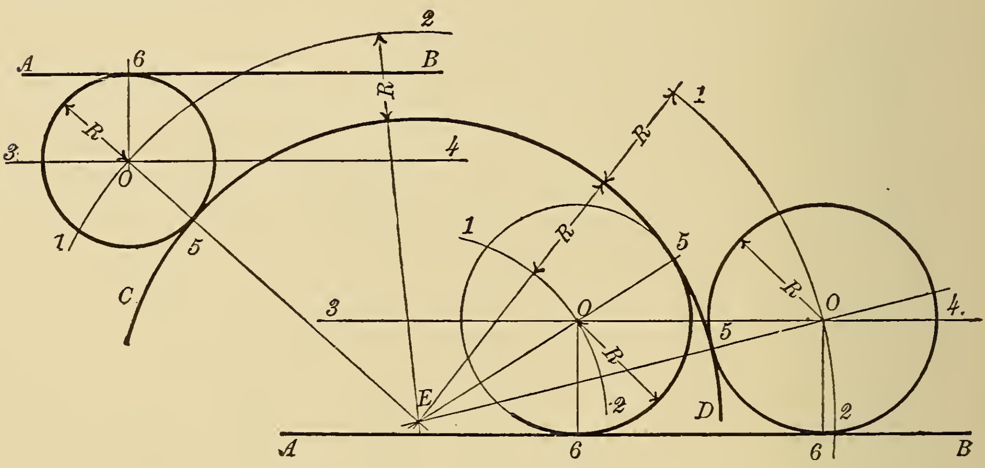


FIG. 63.

Prob. 46. Fig. 64. TO DESCRIBE AN ELLIPSE APPROXIMATELY BY MEANS OF THREE RADII (F. R. Honey's method).—

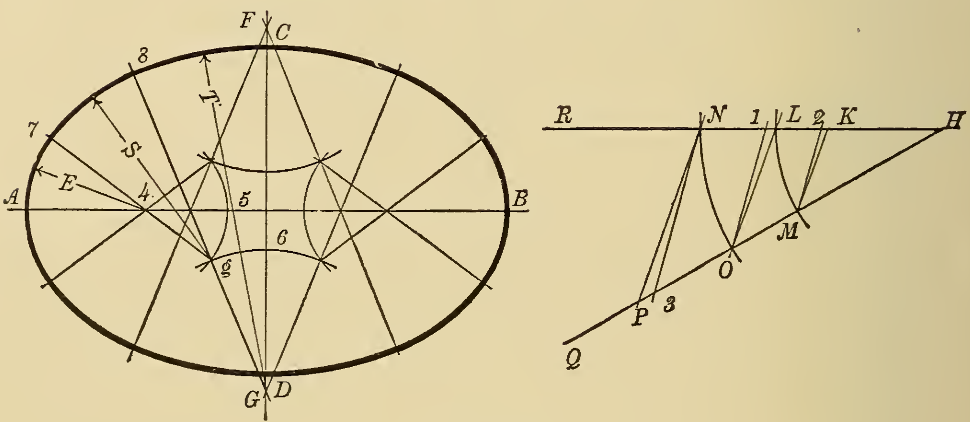


FIG. 64.

Draw straight lines *RH* and *HQ*, making any convenient angle at *H*. With center *H* and radii equal to the semi-minor and

semi-major axes respectively, describe arcs LM and NO. Join LO and draw MK and NP parallel to LO. Lay off $L1 = \frac{1}{8}$ of LN. Join $O1$ and draw $M2$ and $N3$ parallel to $O1$. Take $H3$ for the longest radius ($= T$), $H2$ for the shortest radius ($= E$), and one-half the sum of the semi-axes for the third radius ($= S$), and use these radii to describe the ellipse as follows: Let AB and CD be the major and minor axes. Lay off $A4 = E$ and $A5 = S$. Then lay off $CG = T$ and $C6 = S$. With G as center and $G6$ as radius draw the arc 6, g. With center 4 and radius 4, 5, draw arc 5, g, intersecting 6, g at g. Draw the line Gg and produce it making $G8 = T$. Draw g, 4 and extend it to 7 making g, $7 = S$. With center G and radius GC ($= T$) draw the arc $C8$. With center g and radius g, 8 ($= S$) draw the arc 8, 7. With center 4 and radius 4, 7 ($= E$) draw arc $7A$. The remaining quadrants can be drawn in the same way.

Prob. 47. Fig. 65. TO DRAW AN ELLIPSE HAVING GIVEN THE AXES AB AND CD.—Draw AB and CD at right angles to and bisecting each other at E. With center C and radius EA cut AB in F and F' the foci. Divide EF or EF' into a number of parts as shown at 1, 2, 3, 4, etc. Then with F and F' as centers and $A1$ and $B1$, and $A2$ and $B2$, etc., as radii describe arcs intersecting in R, S, etc., until a sufficient number of points

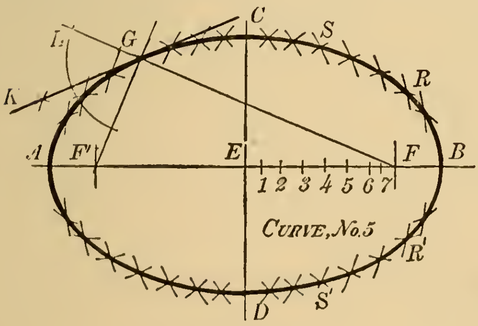


FIG. 65.

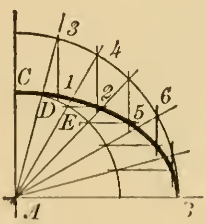


FIG. 66.

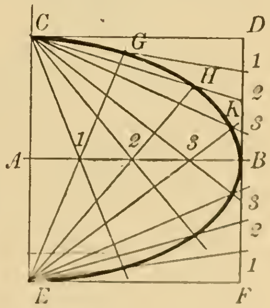


FIG. 67.

are found to draw the elliptic curve accurately throughout. (No. 5 of the "Sibley College Set" of irregular curves is very useful in drawing this curve.) To draw a tangent to the ellipse at the point *G*: Extend *FG* and draw the bisector of the angle *HGF'*. *KG* is the tangent required.

Prob. 48. Fig. 66. ANOTHER METHOD.—Let *AB* and *AC* be the semi axes. With *A* as center and radii *AB* and *AC* describe circles. Draw any radii as *A*3 and *A*4, etc. Make 3 1, 4 2, etc., perpendicular to *AB*, and *D*2, *E*5, etc., parallel to *AB*. Then 1, 2, 5, etc., are points on the curve.

Prob. 49. Fig. 67. ANOTHER METHOD.—Place the diameters as before, and construct the rectangle *CDEF*. Divide *AB* and *DB* and *BF* into the same number of equal parts as 1, 2, 3 and *B*. Draw from *C* through points 1, 2, 3 on *AB* and *BD* lines to meet others drawn from *E* through points 1, 2, 3 on *AB* and *FB* intersecting in points *GHK*. *GHK* are points on the curve.

Prob. 50. Fig. 68. ANOTHER METHOD.—Place the diameters *AB* and *CD* as shown in Drawing No. 1. Draw any convenient

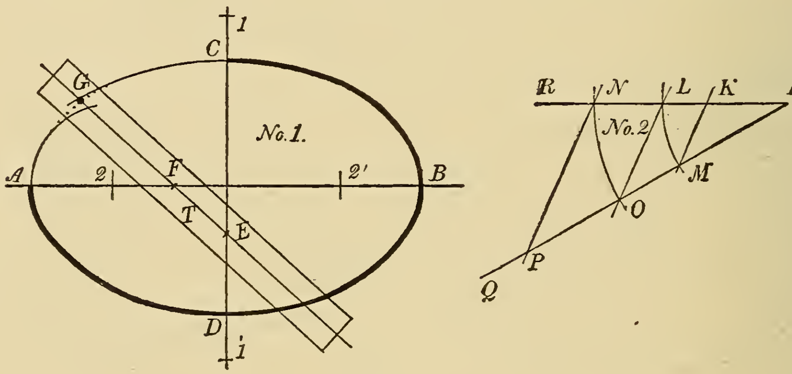


FIG. 68.

angle *RHQ*, Drawing No. 2. With center *H* and radii equal to the semi-minor and semi-major axes describe arcs *LM* and

NO. Join *LO* and draw *MK* and *NP* parallel to *LO.* Then from *C* and *D* with a distance = *HP* lay off the points 1 1′ on the minor axis and from *A* and *B* with a distance = *HK* lay off the points 2 2′ on the major axis. With centers 1, 1′, 2 and 2′ and radii 1–*D* and 2–*B*, respectively, draw arcs of circles. On a piece of transparent celluloid *T* lay off from the point *G*, *GF* and *GE* = the semi-minor and semi-major axes respectively. Place the point *F* on the major axis and the point *E* on the minor axis. If the strip of celluloid is now moved over the figure, so that the point *E* is always in contact with the semi-minor axis and the point *F* with the semi major axis, the necessary number of points may be marked through a small hole in the celluloid at *G* with a sharp conical-pointed pencil, and thus complete the curve of the ellipse between the arcs of circles.

Prob. 51. Fig. 69. To Construct a Parabola, the Base *CD* and the Abscissa *AB* being given.— Draw *EF* through *A* parallel to *CD* and *CE* and *DF* parallel to *AB.* Divide *AE*, *AF*, *EC*, and *FD* into the same number of equal parts. Through the points 1, 2, 3 on *AF* and *AE* draw lines parallel to *AB*, and through *A* draw lines to the points 1, 2, 3 on *FD* and *EC* intersecting the parallel lines in points 4, 5, 6, etc., of the curve.

Prob. 52. Fig. 70. Given the Directrix *BD* and the Focus *C* to Draw a Parabola and a Tangent to It at the Point 3.—The parabola is a curve such that every point in the curve is equally distant from the directrix *BD* and the focus *C.* The vertix *E* is equally distant from the directrix and the focus, i.e. *CE* is = *EB.* Any line parallel to the axis is a diameter. A straight line drawn across the figure at right angles to the

axis is a double ordinate, and either half of it is an ordinate. The distance from C to any point upon the curve, as 2 is always equal to the horizontal distance from that point to the directrix. Thus $C1 = 1, 1'$, $C2$ to $2, 2'$, etc. Through C draw ACF at right angles to BD, ACF is the axis of the

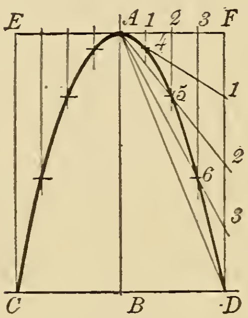


FIG. 69.

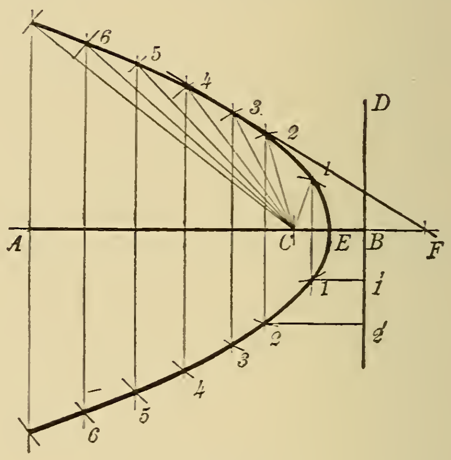


FIG. 70.

curve. Draw parallels to BD through any points in AB, and with center C and radii equal to the horizontal distances of these parallels from BD describe arcs cutting in the points 1, 2, 3, 4, etc. These are points in the curve. The tangent to the curve at the point 3 may be drawn as follows: Produce AB to F. Make $EF =$ the horizontal distance of ordinate 33 from E. Draw the tangent through $3F$.

Prob. 53. Fig. 71. TO DRAW AN HYPERBOLA, HAVING GIVEN THE DIAMETER AB, THE ABSCISSA BD, AND DOUBLE ORDINATE EF.—Make $F4$ parallel and equal to BD. Divide DF and $F4$ into the same number of equal parts. From B draw lines to the points in $4F$ and from A draw lines to the points in DF. Draw the curve through the points where the lines correspondingly numbered intersect each other.

Prob. 54. Fig. 72. TO CONSTRUCT AN OVAL THE WIDTH *AB* BEING GIVEN.—Bisect *AB* by the line *CD* in the point *E*, and with *E* as center and radius *EA* draw a circle cutting *CD* in

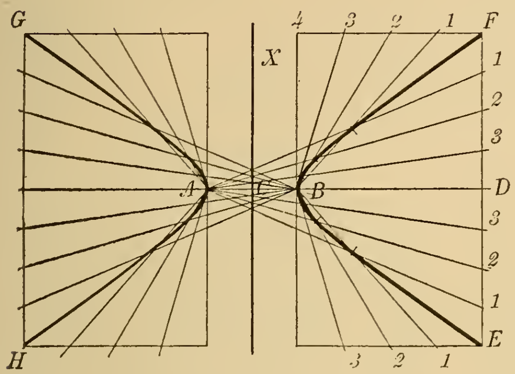


FIG. 71.

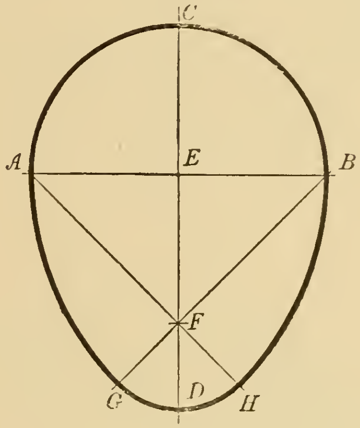


FIG. 72.

F. From *A* and *B* draw lines through *F*. From *A* and *B* with radius equal to *AB* draw arcs cutting the last two lines in *G* and *H*. From *F* with radius *FG* describe the arc *GH* to meet the arcs *AG* and *BH*, which will complete the oval.

Prob. 55. Fig. 73. GIVEN AN ELLIPSE TO FIND THE AXES AND FOCI.—Draw two parallel chords *AB* and *CD*. Bisect each of these in *E* and *F*. Draw *EF* touching the ellipse in 1 and 2. This line divides the ellipse obliquely into equal parts. Bisect 1, 2 in *G*, which will be the center of the ellipse. From *G* with any radius draw a circle cutting the ellipse in *HIJK*. Join these four points and a rectangle will be formed in the ellipse. Lines *LM* and *NO*, bisecting the sides of the rectangle, will be the diameters or axes of the ellipse. With *N* or *O* as centers and radius = *GL* the semi-major axis, describe arcs cutting the major axis in *P* and *Q* the foci.

Prob. 56. Fig. 74. TO CONSTRUCT A SPIRAL OF ONE REVOLUTION.—Describe a circle using the widest limit of the spiral as

a radius. Divide the circle into any number of equal parts as *A*, *B*, *C*, etc. Divide the radius into the same number of equal parts as 1 to 12. From the center with radius 12, 1 describe an arc cutting the radial line *B* in 1′. From the center continue to draw arcs from points 2, 3, 4, etc., cutting the corresponding radii *C*, *D*, *E*, etc. in the points 2′, 3′, 4′, etc. From 12 trace the Archimedes Spiral of one revolution.

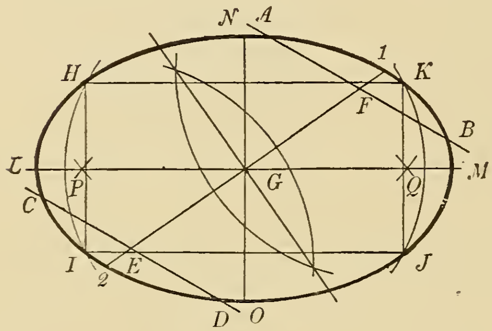


FIG. 73.

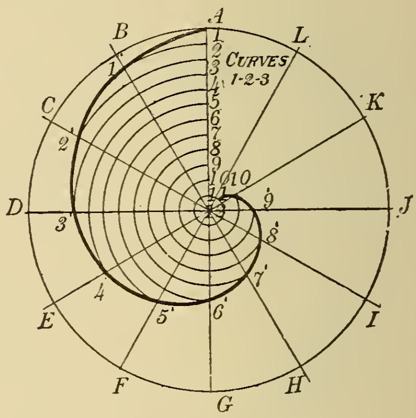


FIG. 74.

Prob. 57. Fig. 75. TO DESCRIBE A SPIRAL OF ANY NUMBER OF REVOLUTIONS, E.G., 2.—Divide the circle into any number of equal parts as *A*, *B*, *C*, etc., and draw radii. Divide the radius *A*12 into a number of equal parts corresponding with the required number of revolutions and divide these into the same number of equal parts as there are radii, viz., 1 to 12. It will be evident that the figure consists of two separate spirals, one from the center of the circle to 12, and one from 12 to *A*. Commence as in the last problem, drawing arcs from 1, 2, 3, etc., to the correspondingly numbered radii, thus obtaining the points marked 1′, 2′, 3′, etc. The first revolution completed, proceed in the same manner to find the points 1″, 2″, 3″, etc. Through these points trace the spiral of two revolutions.

Prob. 58. Fig. 76. To Construct the Involute of the Circle *O*.—Divide the circle into any number of equal parts and draw radii. Draw tangents at right angles to these radii. On the tangent to radius 1 lay off a distance equal to one of the parts into which the circle is divided, and on each of

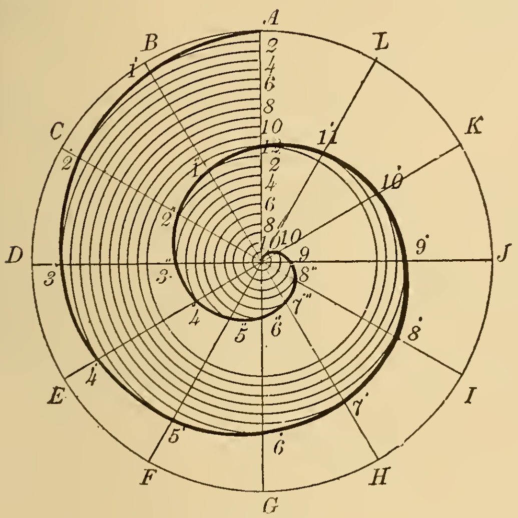


Fig. 75.

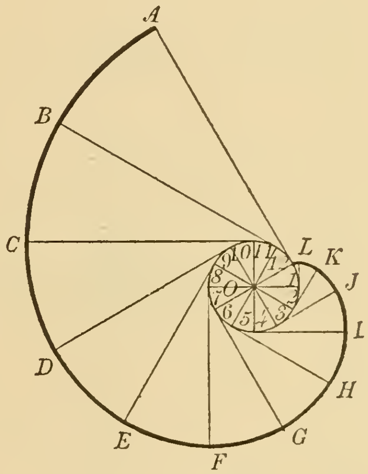


Fig. 76.

the tangents set off the number of parts corresponding to the number of the radii. Tangent 12 will then be the circumference of the circle unrolled, and the curve drawn through the extremities of the other tangents will be the involute.

Prob. 59. Fig. 77. To Describe an Ionic Volute.—Divide the given height into seven equal parts, and through the point 3 the upper extremity of the third division draw 3, 3 perpendicular to *AB*. From any convenient point on 33 as a center, with radius equal to one-half of one of the divisions on *AB*, describe the eye of the volute *NPNM*, shown enlarged at Drawing No. 2. *NN* corresponds to line 3, 3, Drawing No. 1. Make *PM* perpendicular to *NN* and inscribe the square *NPNM*, bisect its sides and draw the square 11, 12,

13, 14. Draw the diagonals 11, 13 and 12, 14 and divide them as shown in Drawing No. 2. At the intersections of the horizontal with the perpendicular full lines locate the points 1, 2, 3, 4, etc., which will be the centers of the quadrants of the outer curve. The centers for the inner curve will be found at the intersections of the horizontal and per-

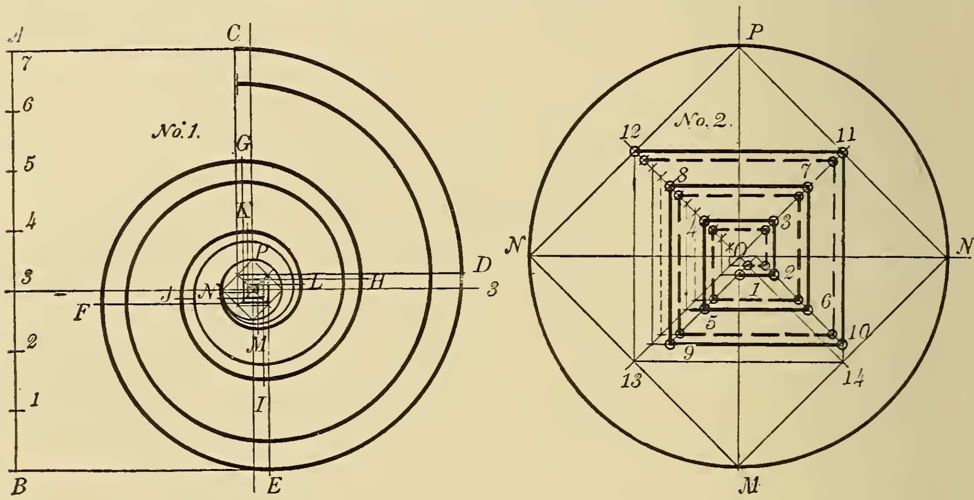


FIG. 77.

pendicular broken lines, drawn through the divisions on the diagonals. Then with center 1 and radius 1*P* draw arc *PN*, and with center 2 and radius 2*N* draw arc *NM*, with center 3 and radius 3*M* draw arc *ML*, etc. The inner curve is drawn in a similar way, by using the points on the diagonals indicated by the broken lines as centers.

Prob. 60. Fig. 78. TO DESCRIBE THE CYCLOID.—*AB* is the director, *CB* the generating circle, *X* a piece of thin transparent celluloid, with one side dull on which to draw the circle *C*. At any point on the circle *C* puncture a small hole with a sharp needle, and place the point *C* tangent to the director *AB* at the point from which the curve is to be drawn. Hold the celluloid at this point with a needle, and rotate it until

the arc of the circle C intersects the director AB. Through the point of intersection stick another needle and rotate X until the circle is again tangent to AB, and through the puncture at C with a 4H pencil, sharpened to a fine conical point, mark the first point on the curve. So proceed until sufficient points have been found to complete the curve.

(NOTE.—The thin celluloid was first used as a drawing instrument by Professor H. D. Williams, of Sibley College, Cornell University.)

Prob. 61. Fig. 79. TO FIND THE LENGTH OF A GIVEN ARC OF A CIRCLE APPROXIMATELY.—Let BC be the given arc. Draw its chord and produce it to A, making BA equal half the

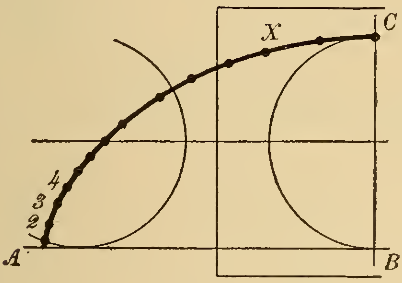


FIG. 78.

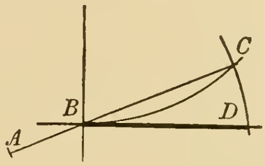


FIG. 79.

chord. With center A and radius AC describe arc CD cutting the tangent line BD at D, and making it equal to the arc BC.

Prob. 62. Fig. 80. TO DESCRIBE THE CYCLOID BY THE OLD METHOD —Divide the director and the generating circle into the same number of equal parts. Through the center a draw ag parallel to AB for the line of centers, and divide it as AB in the points b, c, d, e, f, and g. With centers f, e, d, etc., describe arcs tangent to AB, and through the points of division on the generating circle 1, 2, 3, etc., draw lines parallel to

AB cutting the arcs in the points 1′, 2′, 3′, etc. These will be points in the curve.

An approximate curve may be drawn by arcs of circles. Thus, taking f' as center and $f'g'$ as radius, draw arc $g'1'$.

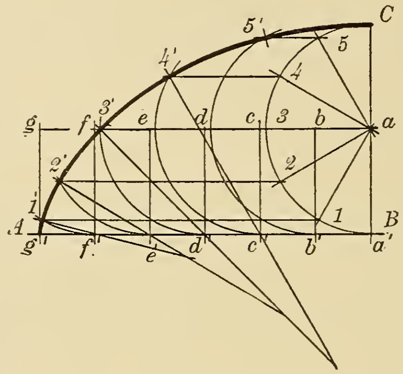


FIG. 80.

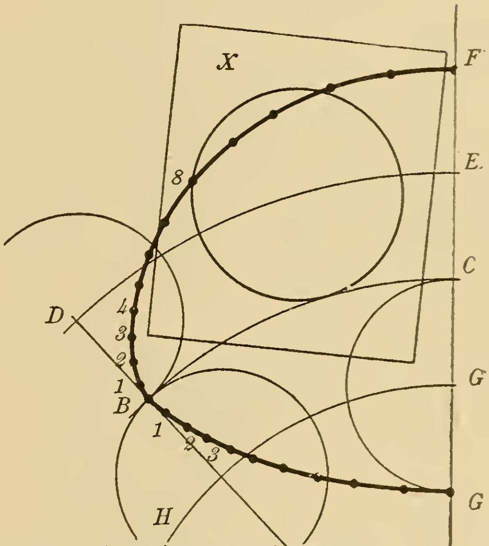
Produce $1'f'$ and $2'e'$ until they meet at the center of the second arc $2'f'$, etc.

Prob. 63. Fig. 81. TO DESCRIBE THE EPICYCLOID AND THE HYPOCYCLOID.—Divide the generating circle into any number of equal parts, 1, 2, 3, etc., and set off these lengths from C on the directing circle CB as e', d', c', etc. From A the center of the directing circle draw lines through e', d', c', etc., cutting the circles of centers in e, d, c, etc. From each of these points as centers describe arcs tangent to the directing circle. From center A draw arcs through the points of division on the generating circle, cutting the arcs of the generating circles in their several positions at the points 1′, 2′, 3′, etc. These will be points in the curve.

Prob. 64. Fig. 82. ANOTHER METHOD.—Draw the generating circle on the celluloid and roll it on the outside of the generating circle BC for the Epicycloid, and on the inside for the

Hypocycloid, marking the points in the curve 1, 2, 3, etc., in similar manner to that described for the Cycloid.

FIG. 82.



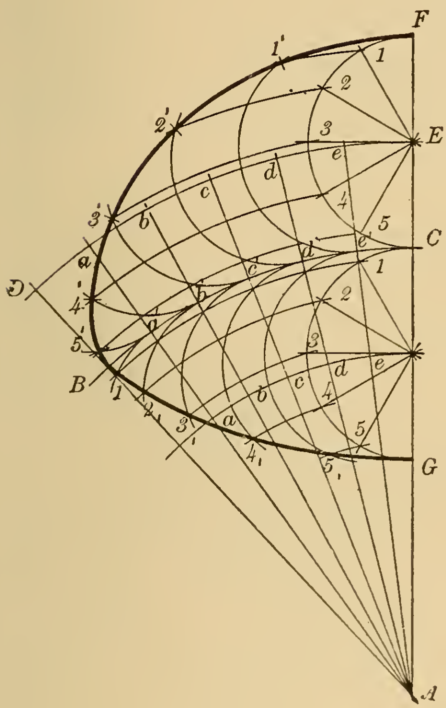


FIG. 81.

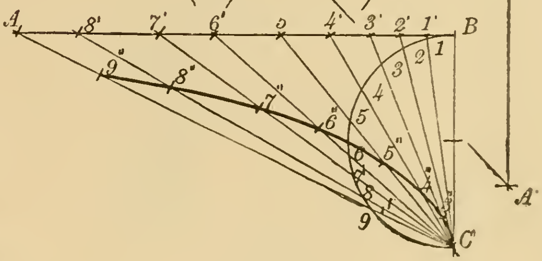


FIG. 83.

Prob. 65. Fig. 83. TO DRAW THE CISSOID.—Draw any line AB and BC perpendicular to it. On BC describe a circle. From the extremity C of the diameter draw any number of lines, at any distance apart, passing through the circle and meeting the line AB in $1'$, $2'$, $3'$, etc. Take the length from A to 9 and set it off from C on the same line to $9''$. Take the distance from $8'$ to 8 and set it off from C on the same line to $8''$, etc., for the other divisions, and through $9''$, $8''$, $7''$, $6''$, etc., draw the curve.

Prob. 66. Fig. 84. To Draw Schiele's Anti-friction Curve. —Let AB be the radius of the shaft and B1, 2, 3, 4, etc., its axis. Set off the radius AB on the straight edge of a piece of stiff paper or thin celluloid and placing the point B on the division 1 of the axis, draw through point A the line A1. Then lower the straight edge until the point B coincides with 2 and the point A just touches the last line drawn, and draw a2, and so proceed to find the points a, b, c, etc. Through these points draw the curve.

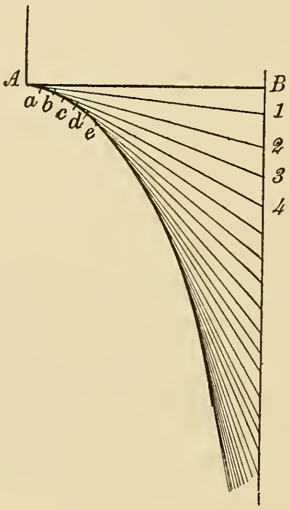


Fig. 84.

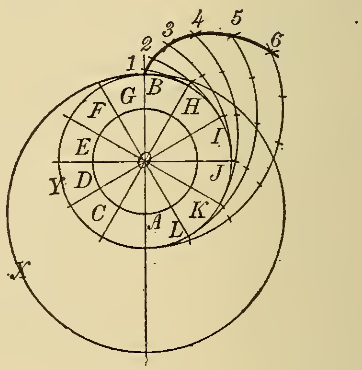


Fig. 85.

Prob. 67. Fig. 85. To Describe an Interior Epicycloid.— Let the large circle X be the generator and the small circle Y the director. Divide circle Y into any number of equal parts, as B, H, I, J, etc. Draw radial lines and make HC, ID, JE, KF, etc., each equal to the radius of the generator X. With centers C, D, E, etc., describe arcs tangent at H, I, J, etc. Make H1 equal to one of the divisions of the director as BH. Make I2 equal to two divisions, J3, three divisions, etc., and draw the curve through the points 1, 2, 3, 4,

etc. This curve may also be described with a piece of celluloid in a similar way to that explained for the cycloid.

It may not be out of place here to describe a few of the

MOULDINGS USED IN ARCHITECTURAL WORK,

since they are often found applied to mechanical constructions.

Prob. 68. Fig. 86. TO DESCRIBE THE "SCOTIA."—1, 1 is the top line and 4, 4 the bottom line. From 1 drop a perpendicular 1, 4; divide this into three equal parts, as 1, 2, and 3. Through the point 2 draw *ab* parallel to 1, 1. With center 2 and radius 2, 1 describe the semicircle *a*1*b*, and with center *b* and radius *ba* describe the arc *a*5 tangent to 4, 4 at 5, draw the fillets 1, 1 and 4, 4.

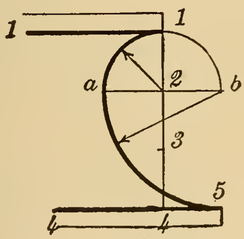


FIG. 86.

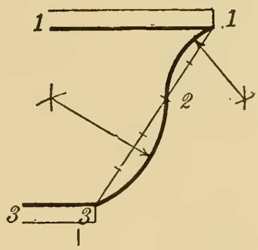


FIG. 87.

Prob. 69. Fig. 87. TO DESCRIBE THE "CYMA RECTA."—Join 1, 3 and divide it into five equal parts, bisect 1, 2 and 2, 3, and with radius equal to 1, 2 and 2, 3 respectively describe arcs 1, 2 and 2, 3. Draw the fillets 1, 1 and 3, 3 and complete the moulding.

Prob. 70. Fig. 88. TO DESCRIBE THE "CAVETTO" OR "HOLLOW."—Divide the perpendicular 1, 2 into three equal parts and make 2, 3 equal to two of these. From centers 1 and 3 with a radius somewhat greater than the half of 1, 3, describe arcs intersecting at the center of the arc 1, 3,

Prob. 71. Fig. 89. To Describe the "Echinus," "Quarter Round," or "Ovolo."—Draw 1, 2 perpendicular to 2, 3, and divide it into three equal parts. Make 2, 3 equal to two of these parts. From the points 2 and 3 with a radius greater than half 1, 3, describe arcs cutting in the center of the required curve.

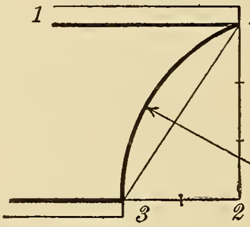


Fig. 88.

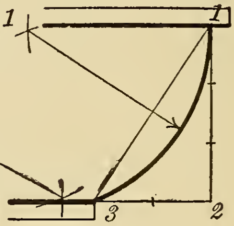


Fig 89.

Prob. 72. Fig. 90. To Describe the "Apophygee."—Divide 3, 4 into four equal parts and lay off five of these parts from 3 to 2. From points 2 and 4 as centers and radius equal to 2, 3, describe arcs intersecting in the center of the curve.

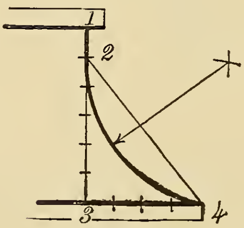


Fig. 90.

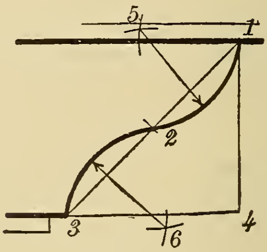


Fig. 91.

Prob. 73. Fig. 91. To Describe the "Cyma Reversa."—Make 4, 3 = 4, 1. Join 1, 3 and bisect it in the point 2. From the points 1, 2 and 3 as centers and radii equal to about two-thirds of 1, 2 draw arcs intersecting at 5 and 6. Points 5 and 6 are the centers of the reverse curves.

Prob. 74. Fig. 92. To Describe the "Torus."—Let 1, 2 be the breadth. Drop the perpendicular 1, 2, and bisect it in the

point 3. With 3 as center and radius 3, 1, describe the semicircle. Draw the fillets.

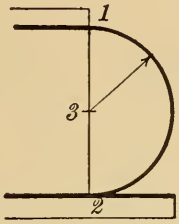


FIG. 92.

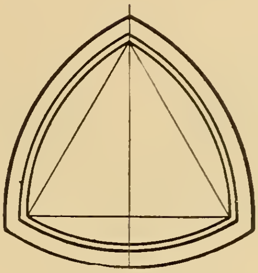


FIG. 93.

Prob. 75. Fig. 93. AN ARCHED WINDOW OPENING.—The curves are all arcs of circles, drawn from the three points of the equilateral triangle, as shown in the figure.

Prob. 76. Fig. 94. TO DESCRIBE THE "TREFOIL."—The equilateral triangle is drawn first, and the angle 1, 2, 3 bisected by the line 2, 4, which also cuts the perpendicnlar line 1, 6 in the point 6. The center of the surrounding circles 1, 2 and 3 are the centers of the trefoil curves.

Prob. 77. Fig. 95. TO DESCRIBE THE "QUATRE FOIL."—Draw the square 1, 2, 3, 4 in the position shown in the figure. The center of the surrounding circles, point 5, is at the intersection of the diagonals of the square. Points 1, 2, 3, 4 of the square are the centers of the small arcs.

Prob. 78. Fig. 96. TO DESCRIBE THE "CINQUEFOIL ORNAMENT." The curves of the cinquefoil are described from the corners of a pentagon 1, 2, 3, 4, 5. Bisect 4, 5 in 6 and draw 2, 6, cutting the perpendicular in the point 7, the center of the large circles.

Prob. 79. Fig. 97. TO DRAW A BALUSTER.—Begin by drawing the center line, and lay off the extreme perpendicular height,

the intermediate, perpendicular, and horizontal dimensions, and finally the curves as shown in the figure.

FIG. 94. FIG. 95. FIG. 96.

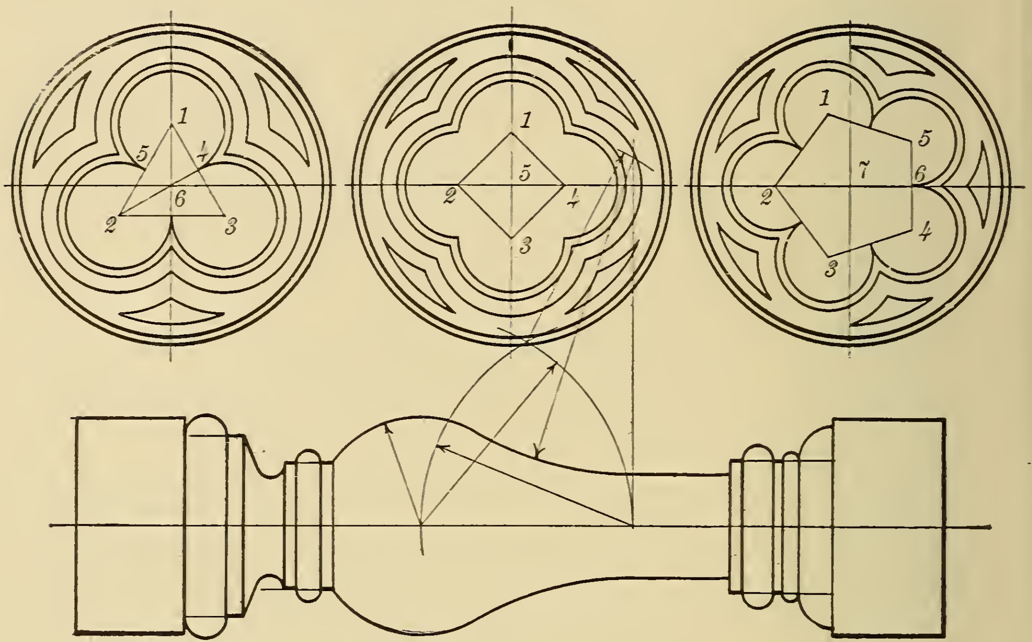


FIG. 97.

DRAWING TO SCALE.

When we speak of a drawing as having been made to scale, we mean that every part of it has been drawn proportionately and accurately, either *full size*, *reduced* or *enlarged.*

Very small and complicated details of machinery are usually drawn enlarged; larger details and small machines may be made full size, while larger machines and large details are shown reduced.

When a drawing of a machine is made to a reduced or enlarged scale the figures placed upon it should always give the full-size dimensions, i.e., the sizes the machine should measure when finished.

Prob. 80. Fig. 98. TO CONSTRUCT A SCALE OF THIRD SIZE OR 4″ = 1 FOOT.—Draw upon a piece of tough white drawing-paper two parallel lines about 1″ apart and about 14″ long as shown by *a*, Fig. 98. From *A* lay off distances equal to 4″ and divide the first space *AB* into 12 equal parts or inches by Prob. 12. Divide *AE* in the same way into as many parts as it may be desired to subdivide the inch divisions on *AB*,

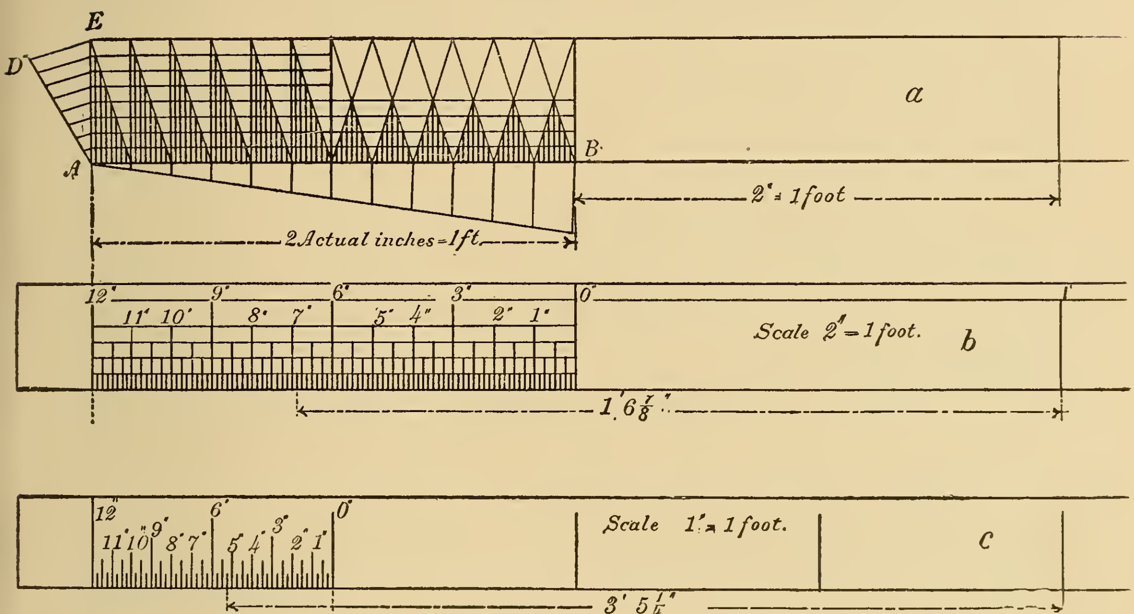


FIG. 98.

usually 8. When the divisions and subdivisions have been carefully and lightly drawn in pencil, as shown by *a*, in Fig. 98, then the lines denoting $\frac{1}{8}''$, $\frac{1}{4}''$, $\frac{1}{2}''$, 1″, and 3″ should be carefully inked and numbered as shown by (*b*). By a further subdivision a scale of 2″ = 1 foot may easily be made as shown by (*c*) in Fig. 98.

CHAPTER III.

CONVENTIONS.

It is often unnecessary if not undesirable to represent certain things as they would actually appear in a drawing, especially when much time and labor is required to make them orthographically true.

So for economic reasons draftsmen have agreed upon conventional methods to represent many things that would otherwise entail much extra labor and expense, and serve no particular purpose.

It is very necessary, however, that all draftsmen should *know how* to draw these things correctly, for occasions will often arise when such knowledge will be demanded; and besides it gives one a feeling of greater satisfaction when using conventional methods to know that he could make them artistically true if it was deemed necessary.

STANDARD CONVENTIONAL SECTION LINES.

Conventional section lines are placed on drawings to distinguish the different kinds of materials used when such drawings are to be finished in pencil, or traced for blue printing, or to be used for a reproduction of any kind.

Water-colors are nearly always used for finished drawings and sometimes for tracings and pencil drawings.

The color tints can be applied in much less time than it

takes to hatch-line a drawing. So that the color method should be used whenever possible.

FIG. 99.—This figure shows a collection of hatch-lined sections that is now the almost universal practice among draftsmen in this and other countries, and may be considered standard.

No. 1. To the right is shown a section of a wall made of *rocks.* When used without color, as in tracing for printing, the rocks are simply shaded with India ink and a 175 Gillott steel pen. For a colored drawing the ground work is made of gamboge or burnt umber. To the left is the conventional representation of water for tracings. For colored drawings a blended wash of Prussian blue is added.

No. 2. *Convention for Marble.*— When colored, the whole section is made thoroughly wet and each stone is then streaked with Payne's gray.

No. 3. *Convention for Chestnut.*— When colored, a ground wash of gamboge with a little crimson lake and burnt umber is used. The colors for graining should be mixed in a separate dish, burnt umber with a little Payne's gray and crimson lake added in equal quantities and made dark enough to form a sufficient contrast to the ground color.

No. 4. *General Convention for Wood.*—When colored the ground work should be made with a light wash of burnt sienna. The graining should be done with a writing-pen and a dark mixture of burnt sienna and a modicum of India ink.

No. 5. *Convention for Black Walnut.*—A mixture of Payne's gray, burnt umber and crimson lake in equal quantities is used for the ground color. The same mixture is used for graining when made dark by adding more burnt umber.

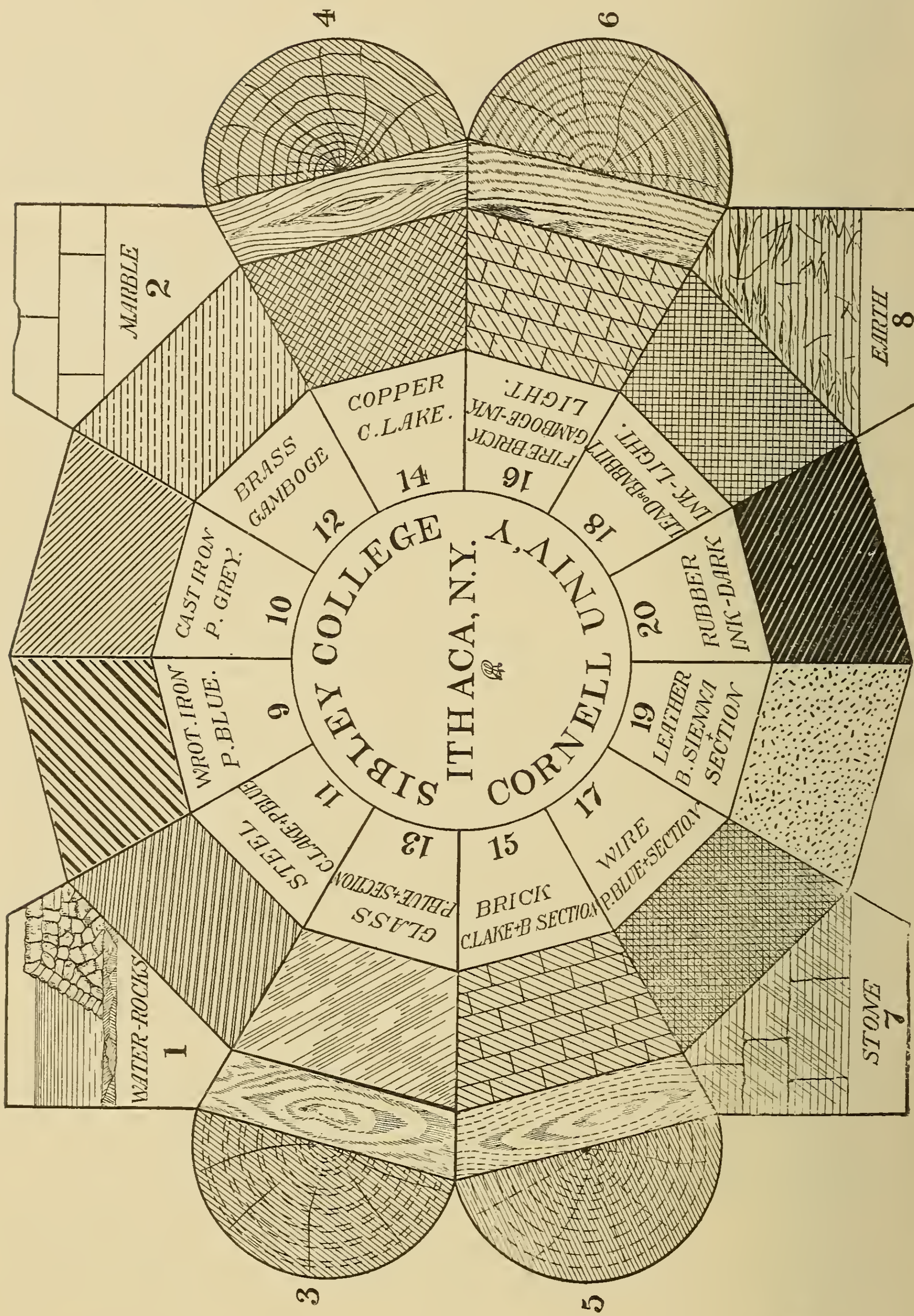

SIBLEY COLLEGE
ITHACA, N.Y.
CORNELL UNIV'Y
1 WATER-ROCKS
2 MARBLE
3
4
5
6
7 STONE
8 EARTH
9 WROT. IRON P. BLUE.
10 CAST IRON P. GREY.
11 STEEL C.LAKE+P.BLUE
12 BRASS GAMBOGE
13 GLASS P.BLUE+SECTION
14 COPPER C.LAKE.
15 BRICK C.LAKE+B SECTION
16 FIRE BRICK GAMBOGE-INK LIGHT.
17 WIRE P.BLUE+SECTION
18 LEAD & BABBITT INK-LIGHT.
19 LEATHER B.SIENNA + SECTION
20 RUBBER INK-DARK

Fig. 99.

No. 6. *Convention for Hard Pine.*— For the ground color make a light wash of crimson lake, burnt umber, and gamboge, equal parts. For graining use a darker mixture of of crimson lake and burnt umber.

No. 7. *Convention for Building-stone.*— The ground color is a light wash of Payne's gray and the shade lines are added mechanically with the drawing-pen or free-hand with the writing-pen.

No. 8. *Convention for Earth.*—Ground color, India ink and neutral tint. The irregular lines to be added with a writing-pen and India ink.

No. 9. *Section Lining for Wrought or Malleable Iron.*— When the drawing is to be tinted, the color used is Prussian blue.

No. 10. *Cast Iron.*—These section lines should be drawn equidistant, not very far apart and narrower than the body lines of the drawing. The tint is Payne's gray.

No. 11. *Steel.*—This section is used for all kinds of steel. The lines should be of the same width as those used for cast-iron and the spaces between the double and single lines should be uniform. The color tint is Prussian blue with enough crimson lake added to make a warm purple.

No. 12. *Brass.*—This section is generally used for all kinds of composition brass, such as gun-metal, yellow metal, bronze metal, Muntz metal, etc. The width of the full lines, dash lines and spaces should all be uniform. The color tint is a light wash of gamboge.

Nos. 13–20.—The section lines and color tints for these numbers are so plainly given in the figure that further instruction would seem to be superfluous.

CONVENTIONAL LINES.

Fig. 100.—There are four kinds:

(1) *The Hidden Line.*—This line should be made of short dashes of uniform length and width, both depending somewhat on the size of the drawing. The width should always be slightly less than the body lines of the drawing, and the

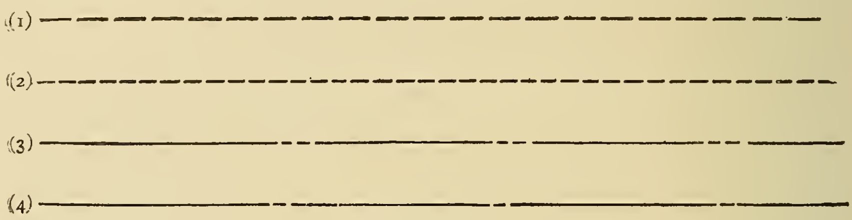


Fig. 100.

length of the dash should never exceed $\frac{1}{8}''$. The spaces between the dashes should all be uniform, quite small, never exceeding $\frac{1}{16}''$. This line is always inked in with *black ink.*

(2) *The Line of Motion.*—This line is used to indicate *point paths.* The dashes should be made shorter than those of the *hidden line*, just a trifle longer than dots. The spaces should of course be short and uniform.

(3) *Center Lines.*—Most drawings of machines and parts of machines are symmetrical about their center lines. When penciling a drawing these lines may be drawn continuous and as fine as possible, but on drawings for reproductions the black-inked line should be a long narrow dash and two short ones alternately. When colored inks are used the center line should be made a continuous *red* line and as fine as it is possible to make it.

(4) *Dimension Lines and Line of Section.*—These lines are made in *black* with a fine long dash and one short dash alternately. In color they should be continuous *blue* lines.

Colored lines should be used wherever feasible, because they are so quickly drawn and when made fine they give the drawing a much neater appearance than when the conventional black lines are used. Colored lines should *never* be broken.

CONVENTIONAL BREAKS.

FIG. 101.—Breaks are used in drawings sometimes to indicate that the thing is actually longer than it is drawn, some-

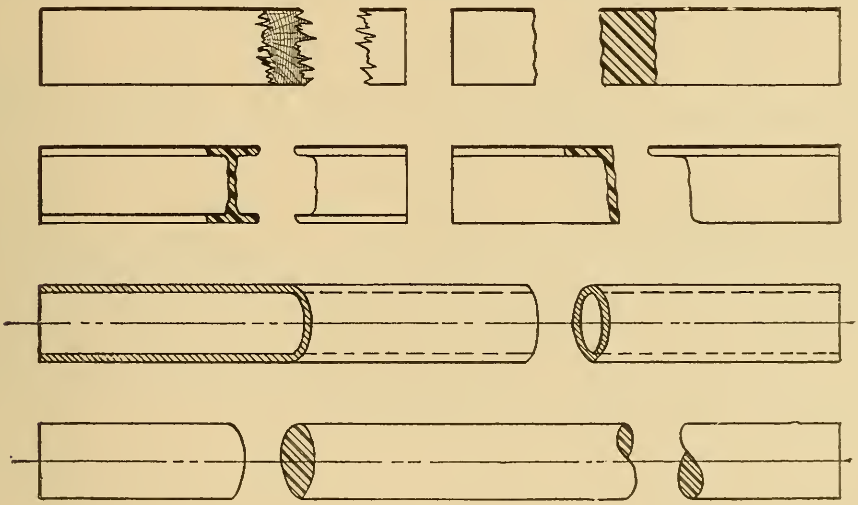


FIG. 101.

times to show the shape of the cross-section and the kind of material. Those given in Fig. 101 show the usual practice.

CROSS-SECTIONS.

FIG. 102.—When a cross-section of a pulley, gear-wheel or other similar object is required and the cutting-plane passes through one of the spokes or arms, then only the rim and hub should be sectioned, as shown at *xx* No. 1 and *zz* No. 2, and the arm or spoke simply outlined. Cross-sections of the arms may be made as shown at *AA* No. 2. In working drawings of

gear-wheels only the number of teeth included in one quadrant need be drawn; the balance is usually shown by conventional lines, e.g., the *pitch* line the same as a center line, viz., a long

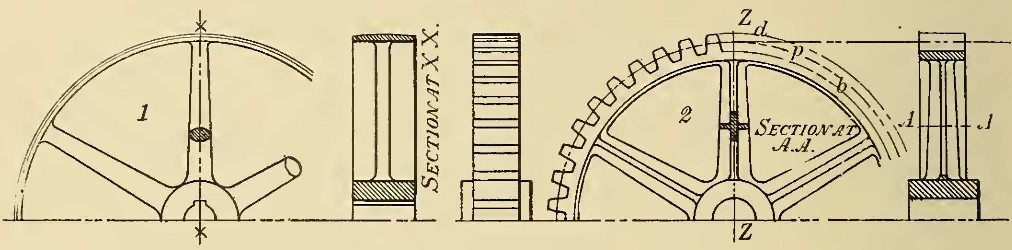


FIG. 102.

dash and two very short ones alternately or a fine continuous *red* line.

The *addendum* line (*d*) and the *root* or *bottom line* (*b*) the same as a dimension line, viz., one long dash and one short dash alternately or a fine continuous *blue* line. The end elevation of the gear-teeth should be made by projecting only the points of the teeth, as shown at No. 2.

CONVENTIONAL METHODS OF SHOWING SCREW-THREADS IN WORKING DRAWINGS.

FIG. 103.—No. 1, shows the convention for a double V thread, U. S. standard; No. 2, a single V thread; No. 3, a single square thread; No. 4, a single left-hand V thread; No. 5, a double right hand square thread; No. 6, any thread of small diameter; No. 7, any thread of very small diameter. The true methods for constructing these threads are explained on pages 99–101, Figs. 137–139.

In No. 6. the short wide line is equal to the diameter of the thread at the bottom. The distance between the

longer narrow lines is equal to the pitch, and the inclination is equal to half the pitch.

The short dash lines in No. 7 should be made to correspond to the diameter of the thread at the bottom. After some practice these lines can be drawn accurately enough by the eye.

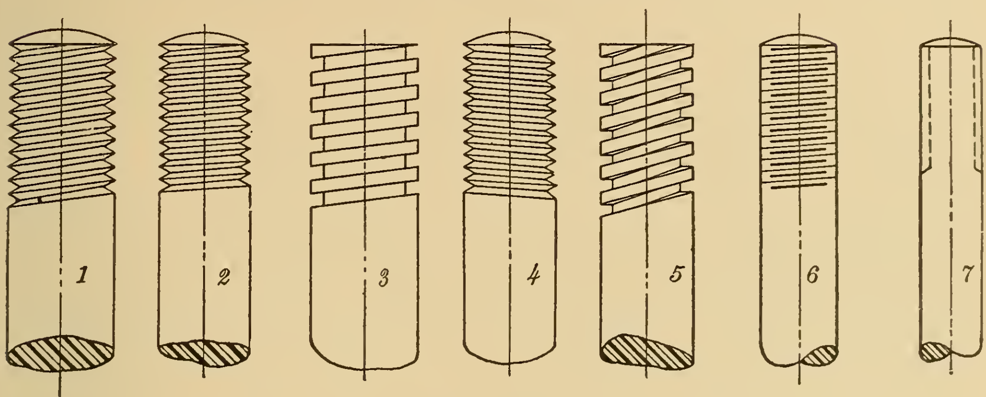


FIG. 103.

CHAPTER IV.

LETTERING AND FIGURING.

THIS subject has not been given the importance it deserves in connection with mechanical drawing. Many otherwise excellent drawings and designs as far as their general appearance is concerned have been spoiled by poor lettering and figuring.

All lettering on mechanical drawings should be plain and legible, but the letters in a title or the figures on a drawing should never be so large as to make them appear more prominent than the drawing itself.

The best form of letter for practical use is that which gives the neatest appearance with a maximum of legibility and requires the least amount of time and labor in its construction.

This would naturally suggest a "free-hand" letter, but before a letter can be constructed "free-hand" with any degree of efficiency, it will be necessary to spend considerable time in acquiring a knowledge of the form and proportions of the particular letter selected.

It is very desirable then that after the student has carefully constructed as many of the following plates of letters and numbers as time will permit and has acquired a sufficient knowledge of the form and proportions of at least the "Roman" and "Gothic" letters; he should then adopt some one

style and practice that at every opportunity, until he has attained some proficiency in its free-hand construction.

When practicing the making of letters and numbers free-hand, they should be made quite large at first so as to train the hand.

The " Roman " is the most legible letter and has the best appearance, but is also the most difficult to make well, either free-hand or mechanically. However, the methods given for its mechanical construction, Figs. 104 and 105, will materially modify the objections to its adoption for lettering mechanical drawings.

The " Gothic " letter is a favorite with mechanical draftsmen, because it is plain and neat and comparatively easy to construct. (See Fig. 106.)

Among the type specimens given in the following pages the Bold-face Roman Italic on page 70 is one of the best for a good, plain, clear, free-hand letter, and is often used with good success on working drawings. Gillott's No. 303 steel pen is the best to use when making this letter free-hand.

The "Yonkers" is a style of letter that is sometimes used for mechanical drawings. It is easy to construct with either F. Soennecken's Round Writing-pens, single point, or the Automatic Shading pen. But it lacks legibility, and is therefore not a universal favorite.

A good style for " Notes" on a drawing is the " Gothic Condensed " shown on page 70.

When making notes on a drawing with this letter, the only guides necessary are two parallel lines, drawn lightly in pencil. The letters should be sketched lightly in pencil first,

and then carefully inked, improving spacing and proportions to satisfy the practiced eye.

FIGURING.

Great care should be taken in figuring or dimensioning a mechanical drawing, and especially a working drawing.

To have a drawing accurately, legibly, and neatly figured is considered by practical men to be the most important part of a working drawing.

There should be absolutely no doubt whatever about the character of a number representing a dimension on a drawing.

Many mistakes have been made, incurring loss in time, labor, and money through a wrong reading of a dimension.

Drawings should be so fully dimensioned that there will be no need for the pattern-maker or machinist to measure any part of them. Indeed, means are taken to prevent him from doing so, because of the liability of the workman to make mistakes, so drawings are often made to scales which are difficult to measure with a common rule, such as 2″ and 4″ = 1 ft.

The following books, among the best of their kind, are recommended to all who desire to pursue further the study of "Lettering": *Plain Lettering*, by Prof. Henry S. Jacoby, Cornell University, Ithaca, N. Y.; *Lettering*, by Charles W. Reinhardt, Chief Draftsman, *Engineering News*, New York; *Free-hand Lettering*, by F. T. Daniels, instructor in C. E. in Tufts College.

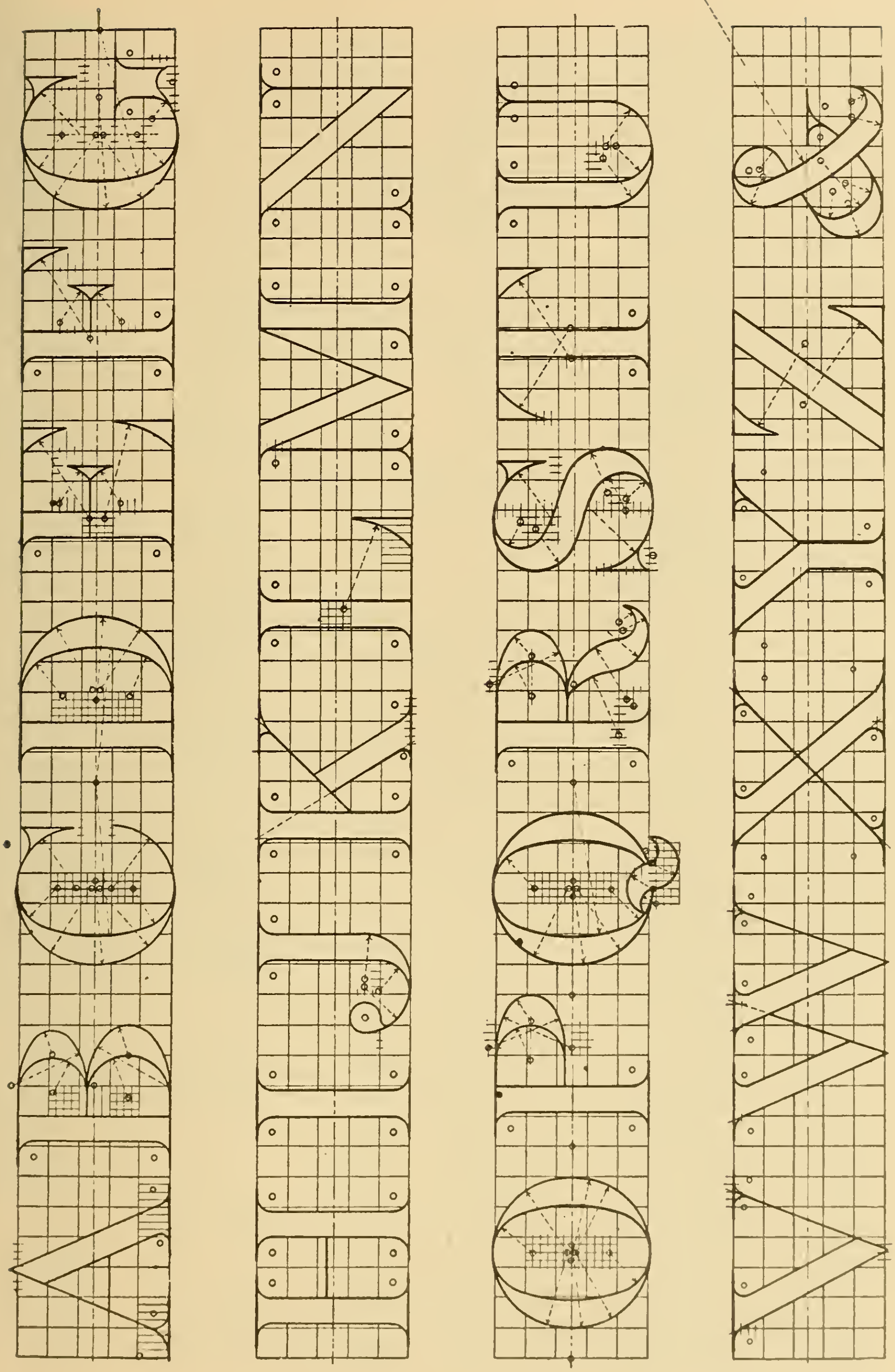


FIG. 104.

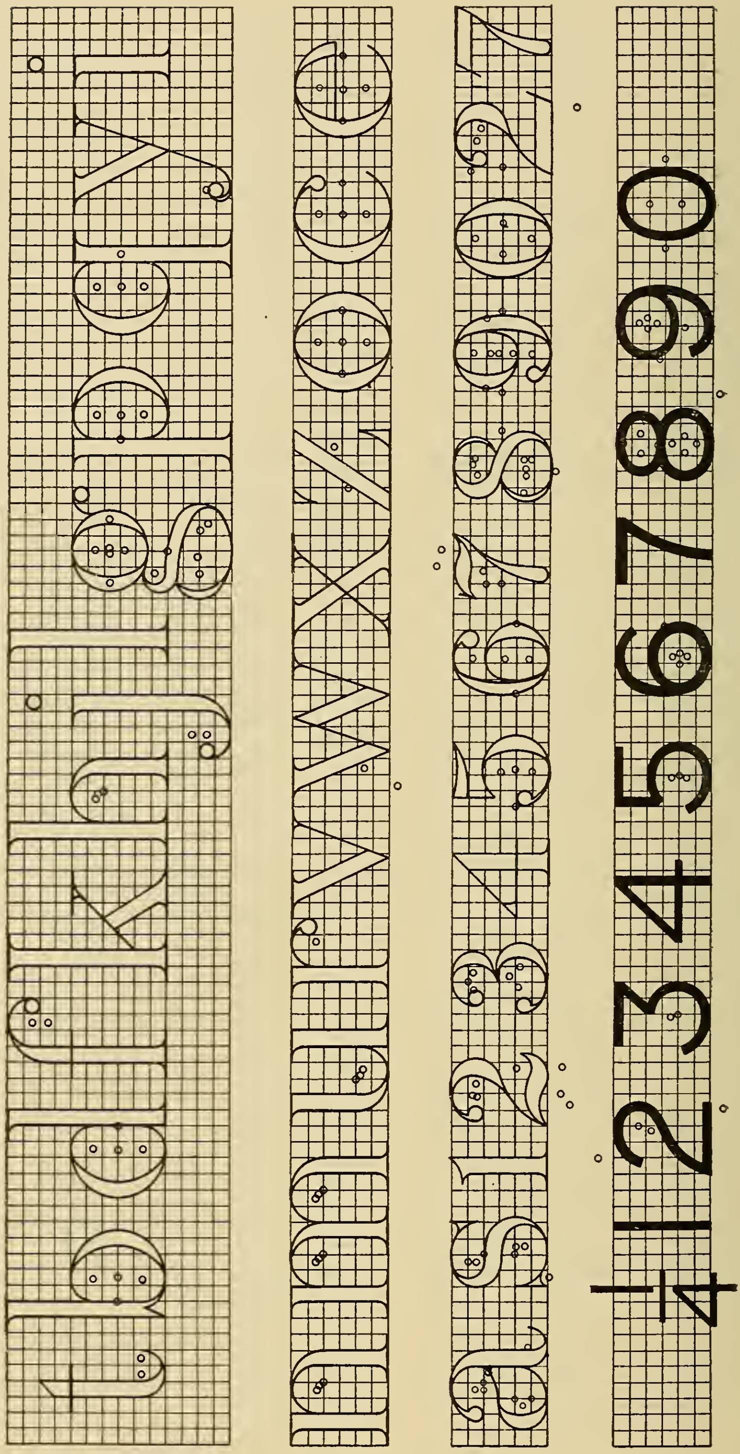


Fig. 105.

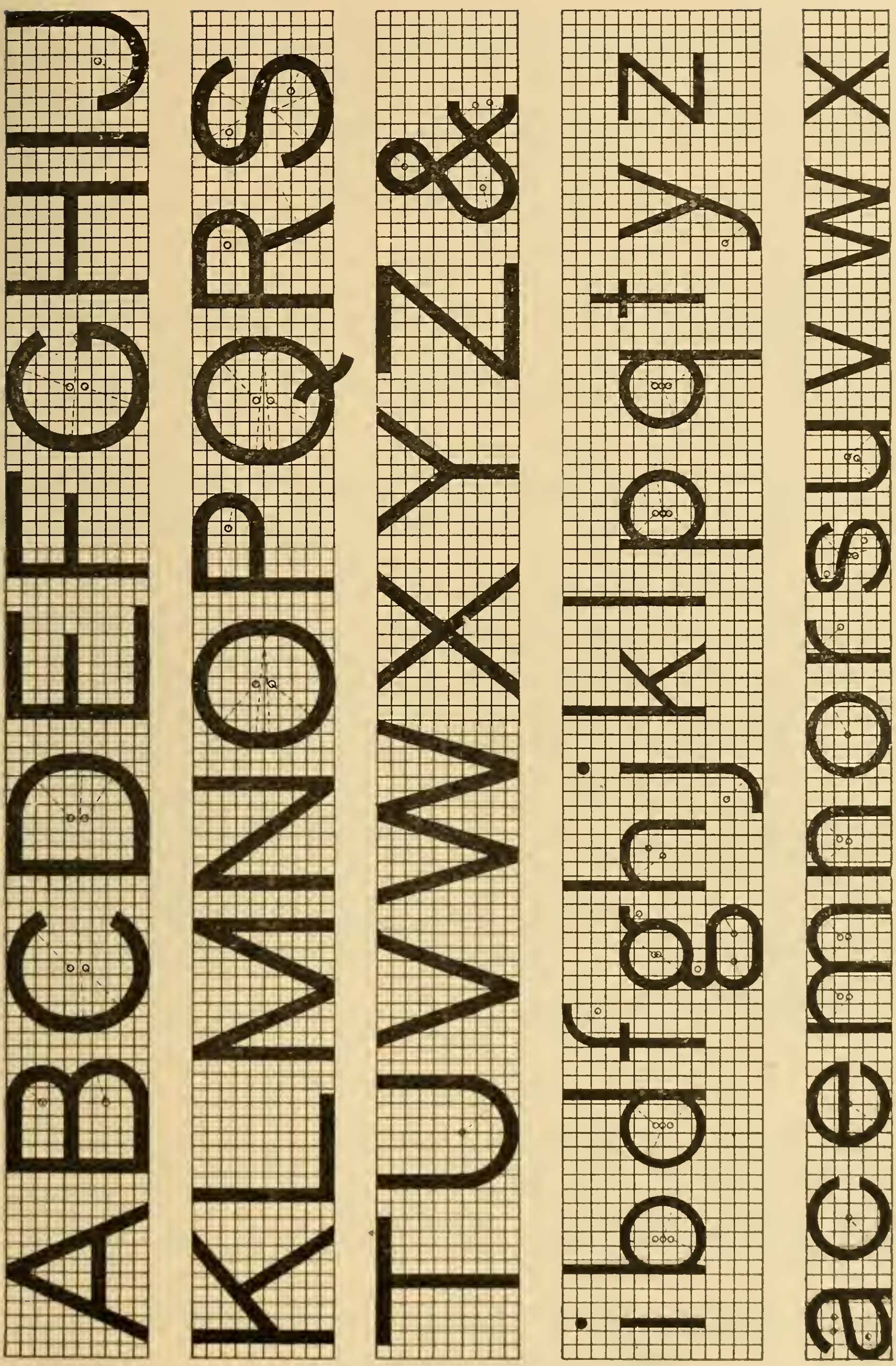

ABCDEFGHIJ
KLMNOPQRS
TUVWXYZ&
ibdfghjklpqtyz
acemnorsuvwx

Fig. 106.

18-Point Roman.

ABCDEFGHIJKLMNOPQRSTUVWX
YZ abcdefghijklmnopqrstuvwxyz
1234567890

18-Point Italic.

ABCDEFGHIJKLMNOPQRSTUV
WXYZ abcdefghijklmnopqrstuvwxyz

12-Point Cushing Italic.

ABCDEFGHIJKLMNOPQRSTUVWXYZ abcdefghijklm
nopqrstuvwxyz 1234567890

28-Point Boldface Italic.

ABCDEFGHIJKLM
NOPQRSTUVWXYZ
abcdefghijklmnopqrstu
vwxyz 1234567890

Two-Line Nonpareil Gothic Condensed.

ABCDEFGHIJKLMNOPQRSTUVWXYZ 1234567890

Three-Line Nonpareil Lightface Celtic.

ABCDEFGHIJKLMNOPQR
STUVWXYZ abcdefghijkl
mnopqrstuvwxyz
1234567890

18-Point Chelsea Circular.

ABCDEFGHIJKLMNOPQRSTUVWX
YZ abcdefghijklmnopqrstuvwxyz
1234567890

18-Point Elandkay.

ABCDEFGHIJKLMNOPQRSTUVWXYZ
1234567890

18-Point Quaint Open.

ABCDEFGHIJKLMNOPQRSTUV
WXYZ 1234567890

28-Point Roman.

ABCDEFGHIJKLM
NOPQRSTUVWXYZ
abcdefghijklmnopqrstu
vwxyz 1234567890

28-Point Old-Style Italic.

ABCDEFGHIJKLMNOP
QRSTUVWXYZ abcdefg
hijklmnopqrstuvwxyz
1234567890

12-Point Victoria Italic.

ABCDEFGHIJKLMNOPQRSTU
VWXYZ 1234567890

18-Point DeVinne Italic.

ABCDEFGHIJKLMNOPQRSTU
VWXYZ abcdefghijklmnopqrst
uvwxyz 1234567890

22-Point Gothic Italic.

ABCDEFGHIJKLMNOPQRSTUVWXYZ
abcdefghijklmnopqrstuvwxyz
1234567890

Double-Pica Program.

ABCDEFGHIJKLMNO
PQRSTUVWXYZ
abcdefghijklmnopqrstuv
wxyz 1234567890

Nonpareil Telescopic Gothic.

ABCDEFGHIJKLMNOPQRSTUVWXYZ 1234567890

24-Point Gallican.

ABCDEFGHIJKL
MNOPQRSTUVW
XYZ 1234567890

Two-Line Virile Open.

ABCDEFGHIJKLMNOPQRSTUVWXYZ
abcdefghijklmnopqrstuvwxyz
1234567890

22-Point Old-Style Roman.

ABCDEFGHIJKLMNOPQRST
UVWXYZ abcdefghijklmnopqrst
uvwxyz 1234567890

36-Point Yonkers.

ABCDEFGHIJKLM
NOPQRSTUVWX
YZ abcdefghijklmnopqr
stuvwxyz 1234567890

CHAPTER V.

ORTHOGRAPHIC PROJECTION.

ORTHOGRAPHIC PROJECTION, sometimes called Descriptive Geometry and sometimes simply Projection, is one of the divisions of descriptive geometry; the other divisions are Spherical Projection, Isometric Projection, Shades and Shadows, and Linear Perspective.

In this course we will take up only a sufficient number of the essential principles of Orthographic Projection, Isometric Projection, and Shades and Shade Lines, to enable the student to make a correct mechanical drawing of a machine or other object.

Orthographic Projection is the science and the art of representing objects on different planes at right angles to each other, by projecting lines from the *point of sight* through the principal points of the object perpendicular to the *Planes of Projection.*

There are commonly three planes of projection used, viz., the *H. P.* or *Horizontal Plane*, the *V. P.* or *Vertical Plane*, and the *Pf. P.* or *Profile Plane.*

These planes, as will be seen by Figs. 107 and 109, intersect each other in a line called the *I. L.* or *Intersecting Line*, and form four angles, known as the first, second, third, and

fourth *Dihedral Angles*. Figs. 107 and 109 are perspective views of these angles.

An object may be situated in any one of the dihedral angles, and its projections drawn on the corresponding co-ordinate planes.

Problems in Descriptive Geometry are usually worked out in the first angle, and nearly all English draftsmen project their drawings in that angle, but in the United States the third angle is used almost exclusively. There is good reason for doing so, as will be shown hereafter.

We will consider first a few projection problems in the first angle, after which the third angle will be used throughout.

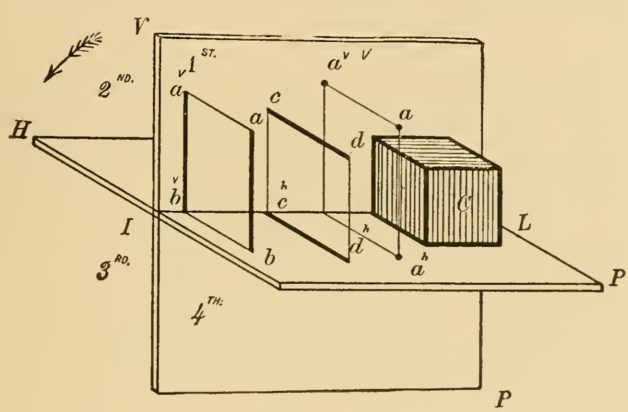


FIG. 107.

H.P., Fig. 107, is the Horizontal Plane, V.P. the Vertical Plane, and I.L. the Intersecting Line.

The Horizontal Projection of a point is where a perpendicular line drawn through the point pierces the H.P.

The Vertical Projection of a point is where a per. line drawn through the point pierces the V.P.

Conceive the point *a*, Fig. 107, to be situated in space 4″ above the H.P. and 3″ in front of the V.P. If a line is passed through the point *a* per. to H.P. and produced until

it pierces the H.P. in the point a^h, a^v will be the Hor. Proj. of the point a.

If another line is projected through the point a per. to the V.P. until it pierces the V.P. in the point a^v, a^v is the vertical projection of the point a.

If now the V.P. is revolved upon its axis I.L. in the direction of the arrow until it coincides with the H.P. and let the H.P. be conceived to coincide with the plane of the drawing-paper, the projections of the point a will appear as shown by Fig. 108.

The vertical projection a^v 4″ above the I.L. and the horizontal projection a^h 3″ below the I.L. both in the same straight line.

In mechanical drawing the vertical projection a^v is called the *Elevation* and the horizontal projection a^h the *Plan*.

The projections of a line are found in a similar manner, by first finding the projections of the two ends of the line, and joining them with a straight line.

Let ab be a line in space $3\frac{1}{2}''$ long, parallel to the V.P. and perpendicular to the H.P. One end is resting on the H.P. $2\frac{1}{2}''$ from the V.P.

The points a and b will be vertically projected in the points a^v and b^v. Join a^vb^v. a^vb^v is the vertical projection of the line ab.

When a line is perpendicular to one of the planes of projection, its projection on that plane is a point, and the projection on the other plane is a line equal to the line itself.

ab, Fig. 107, is perpendicular to the H.P., therefore its proj. on the H.P. when viewed in the direction ab will be seen to be a point.

Conceive now the V.P. revolved as before, the V. proj. will be found to be at $a^v b^v$, Fig. 108, and the H. proj. at the point a^h.

cd, Fig. 107, is a line parallel to the H.P. and perpendicular to the V.P. Its elevation or V. proj. is the point d^v, Fig. 108, and its plan or H. proj. the line $c^h d^h$ perpendicular to the Intersecting Line and equal in size to the line itself.

Planes or Plane Surfaces bounded by lines are projected by the same principles used to project lines and points.

Let $aa^v b^v b$, Fig. 107, be a plane at right angles to and touching both planes of projection.

The elevation of the front upper corner a is projected in the point a^v. The elevation of the front lower corner b is projected in the point b^v. Join $a^v b^v$. $a^v b^v$ is the vertical projection of the front edge ab of the plane. The plan of the front

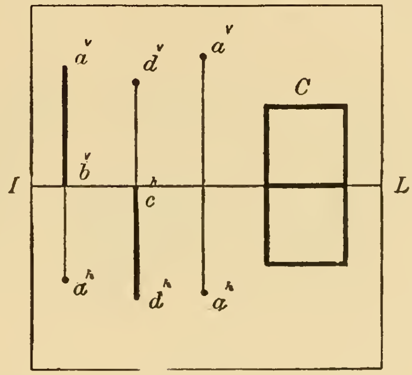


FIG. 108.

upper corner is projected in the point b and the point a^v in the point b^v. A straight line joining bb^v is the plan or horizontal projection of the top edge of the plane.

On the drawing-paper the plan and elevation of the plane $aa^v b\ a$ would be shown as a continuous straight line a^v to a^h Fig. 108.

Solids bounded by plane surfaces are projected by means of the same principles used to project planes, lines, and points.

C, Fig. 107, is a cube bounded by six equal sides or surfaces. The top and bottom being parallel to the H.P. and the front and back parallel to the V.P., the vert. proj. is a square above I.L. equal in area to any one of the six faces of the cube. The hor. proj. is a similar square below I.L.

These projections are shown at *C*, Fig. 108, as they would appear on the drawing-paper.

The foregoing illustrates a few of the simple principles of projection in relation to points, lines, and solids when placed in the first dihedral angle, and we find that the plan is always *below* and the elevation always *above* the I.L.

Let us now consider the same problems when situated in the *third* angle. The point *a*, Fig. 109, is behind of the V.P.

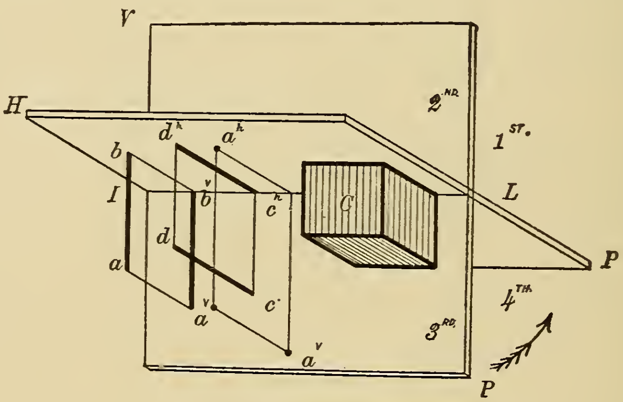


Fig. 109.

and below the H.P. Draw through *a* perpendiculars to the plane of projection. The Hor. proj. is found at a^h and the vert. proj. at a^v.

Conceive again the V.P. to be revolved in the direction of the arrow until it coincides with the H. P. The hor. proj.

will then appear at a^h *above* the I.L. and the vert. proj. at a^v *below* the I.L., Fig. 110. And so with the lines, the planes, and the solids.

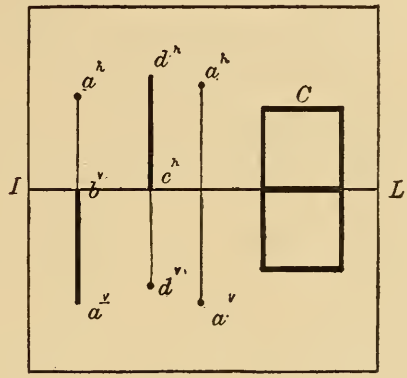


FIG. 110.

In order to still further explain the use of the planes of projection, with regard to objects placed in the third angle, let us suppose a truncated pyramid surrounded by imaginary planes at right angles to each other, as shown by Fig. 111.

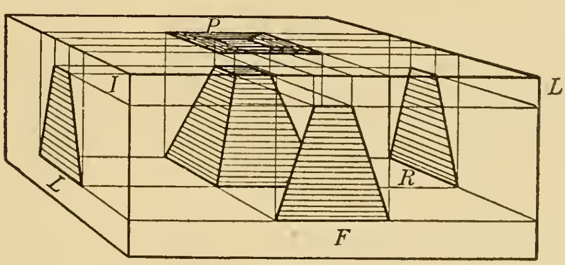


FIG. 111.

With a little attention it will easily be discerned that the pyramid is situated in the third dihedral angle, and that in addition to the V. and H. planes, we have passed two profile planes at right angles to the V. and H. planes, one at the right-hand and one at the left.

When the pyramid is viewed orthographically through each of the surrounding planes, four separate views are had,

exactly as shown by the projections on the opposite planes, viz., a Front View, Elevation, or Vert. Proj. at F.; a Right-hand View, Right-end Elevation, or Right-profile Projection at R.; a Left-hand View, Left-end Elevation, or Left-profile Projection at L.; a Top View, Plan or H. Proj. at P.

If we now consider the V.P. and the right and left profile planes to be revolved toward the beholder until they coincide, using the front intersecting lines as axes, the projections of the pyramid will be seen as shown by Fig. 112, which when the

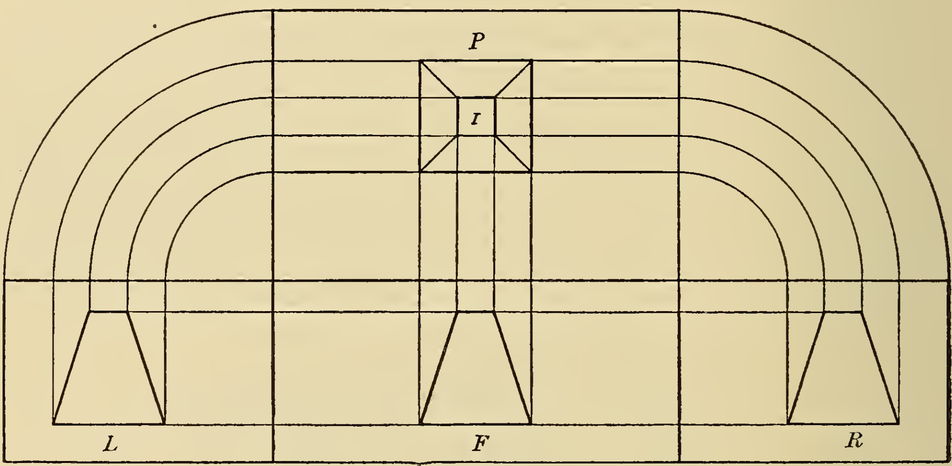


FIG. 112.

imaginary planes and projecting lines have been removed, will be a True Drawing or Orthographic Projection of the truncated pyramid.

NOTATION.

In the drawings illustrating the following problems and their solutions the *given* and *required* lines are shown *wide* and *black*. *Hidden* lines are shown *broken* into short dashes a little narrower than the *visible* lines. *Construction* or *projection* lines are drawn with very narrow *full* or *continuous* black lines.

When convenient very narrow, continuous *blue* lines are sometimes used.

The Horizontal Plane is known as the H.P., the Vertical Plane as V.P. and the Profile Plane as Pf.P.

A point in space is designated by a small letter or figure, their projection by the same letters or figures with small h or v written above for the horizontal or vertical projection respectively.

In some complicated problems where points are designated by figures their projections are named by the same figures accented.

Drawings should be carefully made to the dimensions given, the scale to be determined by the instructor.

The student should continually endeavor to improve in inking straight lines, curves, and joints.

In solving the following problems the student should have a model of the co-ordinate planes for his own use. This can be made by taking two pieces of stiff cardboard and cutting a slot in the center of one of them large enongh to pass the folded half of the other through it; when unfolding this half a model will be had like that shown by Fig. 107 or 109.

All projections shall now be made from the third, dihedral angle.

PROB. 1.—A point a is situated in the third dihedral angle, 1″ below the H.P. and 3″ behind the V.P.

It is required to draw its vertical and horizontal projections.

Draw a straight line $a^h a^v$, Fig. 113, perpendicular to I.L. and measure off the point a^v 1″ below I.L. and the point a^h 3″ above I.L.

a^v is the vertical and a^h the horizontal projection in the same straight line $a^v a^h$.

The student should demonstrate this with his model.

PROB. 2.—Draw two projections of a line 3″ long parallel to both planes, ¾″ below the H.P. and 2″ behind the V.P.

As the line is parallel to both planes, both projections will be parallel to the I.L.

Draw $a^v b^v$ the vert. proj. of the line 3″ long, Fig. 114, parallel to I.L. and ¾″ below it. Draw the hor. proj. 2″ above the I.L. and parallel to it, making it the same length as the

FIG. 113.

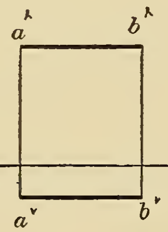


FIG. 114.

FIG. 115.

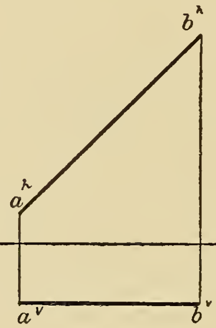


FIG. 116.

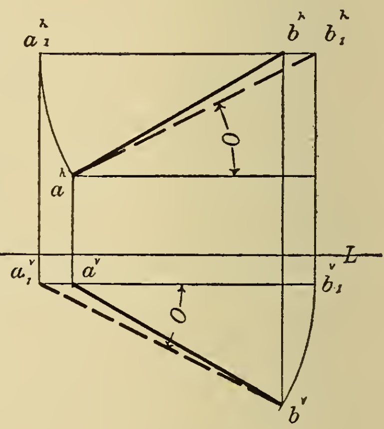


FIG. 117.

vert. proj. by drawing lines perpendicular to I.L. from the points a^v and b^v to a^h and b^h.

PROB. 3.—To draw the hor. and vert. projs. of a straight line 3″ long, per. to the vert. plane, Fig. 115.

As the line is per. to the vert. plane the vert. proj. will be a point below the I.L. and the hor. proj. will be parallel to the horizontal plane and per. to I.L.

PROB. 4.—To draw the plan and elevation of a straight line 6″ long making an angle of 45° with the vert. plane and and par. to the hor. plane, Fig. 116.

The plan or hor. proj. will be above the I.L. and make an angle of 45° with it. The elevation or vert. proj. will be below and par. to I.L.

Draw from the point a^h at any convenient distance from I.L. a straight line $a^h b^h$ 6″ long, making an angle 45° with I.L.

Draw $a^v b^v$ par. to I.L. at a convenient distance below it. The length of the elevation or vert. proj. is determined by dropping perpendiculars from the end of the hor. proj. $a^h b^h$ to the points $a^v b^v$.

PROB. 5, FIG. 117.—To find the true length of a straight line oblique to both planes of projection and the angle it makes with these planes.

$a^v b^v$ and $a^h b^h$ are the projections of a straight line oblique to V.P. and H.P. Using a^v as a pivot, revolve the line $a^v b^v$ until it becomes parallel to I.L. as shown by $a^v b_1^v$. From the point b_1^v erect a per. Through the point b^h draw a line par. to I.L. cutting the per. in the point b_1^h.

The broken line $a^h b_1^h$ is the true length of the line ab, and the angle o is the true angle which the line makes with V.P.

To find the angle it makes with H.P. :

Using b^h as a pivot, revolve the line $b^h a^h$ until it becomes par. to I.L. as shown by $b^h a_1^h$. From the point a_1^h drop a per. Through the point a^v draw a line par. to I.L. intersecting the per. at the point $a_1^v o$ is the angle which the line ab makes with H.P. and the broken line $a_1^v b^v$ is again its true length.

PROB. 6, FIG. 118.—To project a plane surface of given size, situated in the third angle and par. to the V.P.

Let $abcd$ be the plane surface 3″ long × 2″ wide. If we conceive lines to be projected from the four corners of the

plane surface to the V.P. and join them with straight lines we will have its V. projection $a^v b^v c^v d^v$ and shown by Fig. 118. And as the plane surface is par. to the V P. it must be per to the H.P. since the planes of projection are at right angles to each other. So the plan or H. projection will be a straight line equal in length to one of the sides of the plane surface.

At a convenient distance above I.L. draw a straight line, and from the points $a^v b^v$ project lines at right angles to I.L., cutting the straight line in the points $a^h b.^h$ The line $a^h b^h$ is the hor. proj. of the plane surface *abcd.*

PROB. 7, FIG. 118.—To draw the projections of a plane surface of given dimensions when situated in the third angle perpendicular to the H.P. and making an angle with the V.P.

Let the plane surface be $3'' \times 2''$ as before and let the angle it makes with V.P. be 60°.

To draw the plan:

At a convenient distance above I.L. and making an angle of 60° with it, draw $a^h b_1{}^h$, Fig. 118, 2″ long. From $b_1{}^h$ drop a per. cutting $a^v b^v$ in the point $b_1{}^v$ and $c^v d^v$ in the point $d_1{}^v$, then the rectangle $a^v b_1{}^v d_1{}^v c^v$ will be the vert. proj. or elevation of the plane surface *abcd.*

PROB. 8, FIG. 119.—To draw the projections of the same plane surface (1) when parallel to the H.P., (2) when making an angle of 30° with H.P. and per. to V.P., (3) when making an angle of 60° with H.P. and per. to V.P., and (4) when per. to both planes.

Fig. 119 shows the projections; further explanations are unnecessary.

PROB. 9, FIGS. 119 AND 120.—To draw the projections of

the same plane surface when making compound angles with the planes of projection.

Let the plane make an angle of 30° with H.P., as in the second position of Prob. 8, Fig. 119, and in addition to that, revolve it through at angle of 30°. First, draw the plane parallel to H.P., as shown by $a^hc^hb^hd^h$, Fig. 119, the true size of the plane.

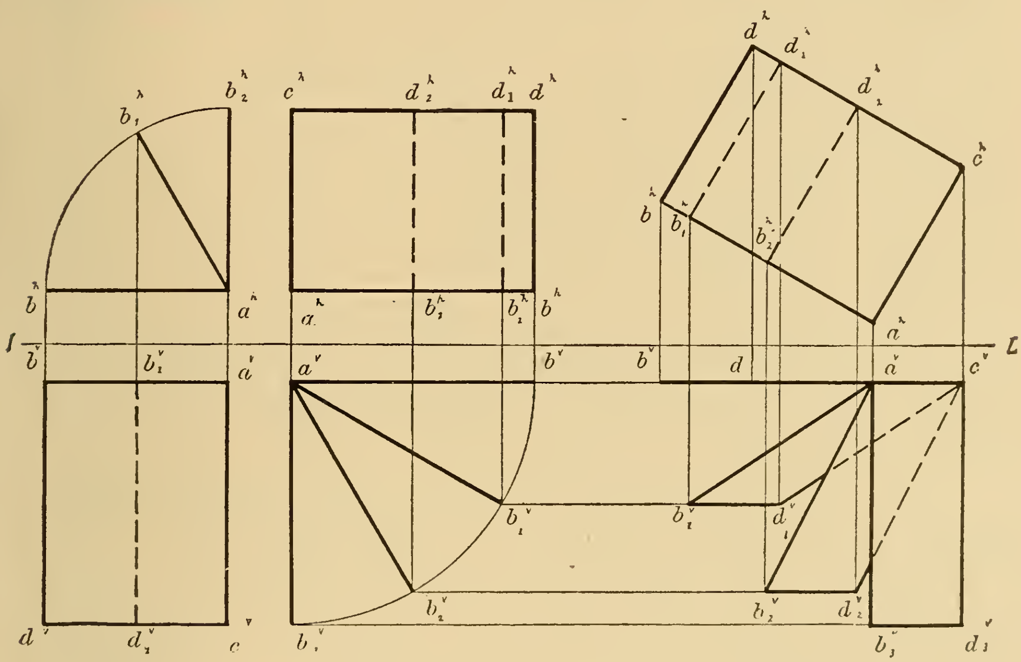


FIG. 118. FIG. 119. FIG. 120.

Its elevation will be the straight line a^vb^v parallel to I.L. Next revolve a^vb^v, using a^v as a pivot, through an angle of 30°, to the position $a^vb_1^v$, which is its vert. proj. when making an angle of 30° with H.P. Its plan is projected in $a^hb_1^hc^hd_1^h$.

Now as the plane is still to make an angle of 30° with H.P. after it has been revolved through an angle of 30° with relation to the V.P., its hor. proj. will remain unchanged.

With a piece of celluloid or tracing-paper trace the hor. proj. $a^hb_1^hc^hd_1^h$, lettering the points as shown, and revolve the

tracing through the angle of 30°, or, which is the same thing, place the tracing so that the line $a^h c^h$ will make an angle of 60° with I.L., and with a sharp conical-pointed pencil transfer the four points to the drawing-paper and join them by straight lines, as shown by Fig. 120.

And as the line $a^h c^h$ retains its position relative to H.P. after the revolution, its elevation will be found at $a^v c^v$, Fig. 120, in a straight line drawn through $a^v b^v$, Fig. 119, intersecting perpendiculars from $a^h c^h$, Fig. 120. And the vert. proj. of the points $b_1^h d_1^h$ will be found at $b_1^v d_1^v$, Fig. 120, in a straight line drawn through b_1^v, Fig. 119, parallel to I.L. and intersecting pers. from $b_1^h d_1^h$, join with straight lines the points $a^v b_1^v c^v d_1^v$.

Draw the projections of the plane when making an angle of 60° with H.P. and revolved through an angle of 30° with relation to V.P.

Draw the projections of the plane when making an angle of 60° with the V.P. and per. to the H.P., Fig. 120.

PROB. 10.—To draw the projections of a plane surface of hexagonal form in the following positions: (1) When one of its diagonals is par. to the V.P. and making an angle of 45° with the H.P. (2) When still making an angle of 45° with the H.P. the same diagonal has been revolved through an angle of 60°.

Draw the hexagon $1^h 2^h 3^h 4^h 5^h 6^h$, Fig. 121, at any convenient distance above I.L., making the inscribed circle $= 2\frac{1}{2}''$. This will be its hor. proj. and $2^v 4^v 6^v 1^v$ its vert. proj., the diagonal $1^h 2^h$ being par. to both planes of proj. With 1^v as an axis revolve $6^v 4^v 2^v$ through an angle of 45°. Through the points $2_1^v 4_1^v 6_1^v$ erect pers. to the points $6_1^h 5_1^h 4_1^h 3_1^h$ and 2_1^h

and join them with straight lines. These are the projs. in the first position. Now trace the hor. proj, 1^h, $2_1{}^h$, etc., on a piece of celluloid or tracing-paper and revolve the tracing until the diagonal $1^h 2_1{}^h$ makes an angle of 60° with the I.L., Fig. 122. Next draw pers. from the 6 points of the hexagonal plane to intersect hors. from the corresponding points of the elevation in Fig. 121, join the points of intersection with

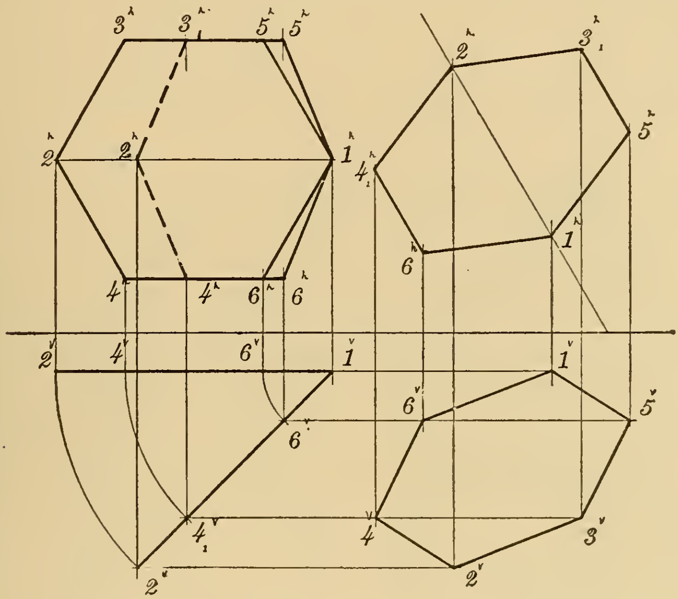


FIG. 121. FIG. 122.

straight lines, and so complete the projections of the second position, Fig. 122.

PROB. 11, FIGS. 123 AND 124.—Draw the projs. of a circular plane (1) when its surface is par. to the vert. plane, (2) when it makes an angle of 45° with the V.P., and (3) when still making an angle of 45° with the V.P. it has been revolved through an angle of 60°.

First position: Draw the circular plane 1^v, 2^v, 3^v, 4^v, etc., Fig. 123, below the I.L. with a radius $= 1\frac{1}{2}''$ and divide and figure it as shown.

Since the plane is par. to V.P. its hor. proj. will be a straight line 1^h, 2^h, ... etc.

For the second position revolve the said hor. proj. through the required angle of 45° to the position a^h . . . . 1_1^h, Fig. 123, and through each division in 1^h . . . . a^h draw arcs cutting a^h . . . . 1^h in points $2^h 3^h$ . . . This is the hor. proj. of the plane when making an angle of 45° with the V.P.

The elevation is found by dropping pers. from the points in the hor. proj. a^h . . . 1_1^h to intersect hor. lines drawn through the correspondingly numbered points in the eleva-

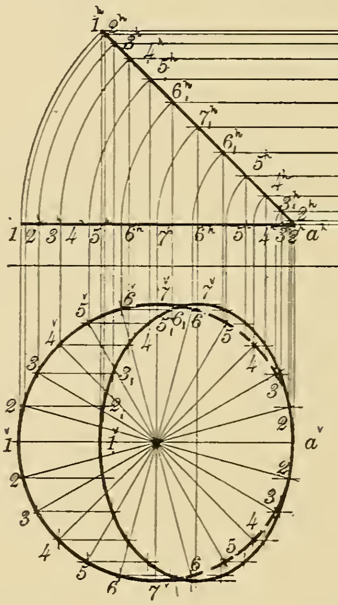


FIG. 123.

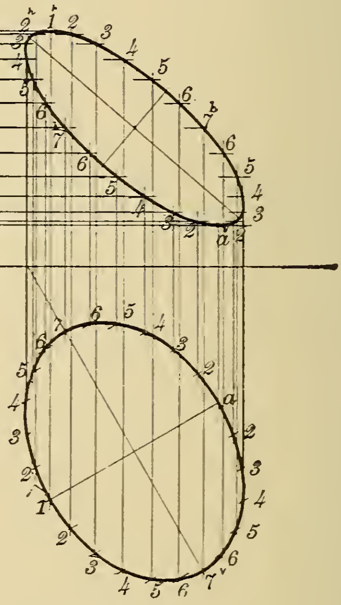


FIG. 124.

tion and through these intersections draw the elevation or vert. proj. of the second position.

For the third position make a tracing of the elevation of the second position, numbering all the points as before, and place the tracing so that the diameter $7^v 7^v$ makes the required angle of 60° with the I.L. and transfer to the drawing-paper.

The result will be the elevation of the third position shown below the I.L., Fig. 124. Its hor. proj. is found by drawing pers. through the points 1, 2, 3, 4 . . . to intersect hors. drawn through the corresponding points in the hor. proj. of the 2d position and through these intersections draw the plan or hor. proj. of the third position, Fig. 124.

PROB. 12, FIG. 125.—Draw the projs. of a regular hexagonal prism, 3″ high and having an inscribed circle of $4\frac{5}{8}''$ diam.: (1) When its axis is par. to the V.P. (2) Draw the true form of a section of the prism when cut by a plane passing through it at an angle of 30° with its base. (3) Draw the projection of a section when cut by a plane passing through *XX*, Fig. 125, per. to both planes of proj.

The drawing of the I.L. may now be omitted.

For the plan of the first part of this prob. draw a circle with a radius = to $2\frac{5}{16}''$, and circumscribe a hexagon about it, as shown by a^h, b^h, b^h, etc., Fig. 125. To project the elevation, draw at a convenient distance from the plan a hor. line par. to a^hd^h, and 3″ below it another line par. to it. From the points $a^hb^hc^hd^h$, drop pers. cutting these par. lines in the points $a^vb^vc^vd^v$, thus completing the elevation of the prism.

Second condition: Draw the edge view or trace of the cutting plane 1′4′, making an angle of 30° with the base of the prism, locating the lower end 4′ one-half inch above the base; parallel to 1′4′, and at a convenient distance from it draw a straight line 1, 4; at a distance of $2\frac{5}{16}''$ on each side of 1, 4 draw lines 3, 2 and 5, 6 parallel to 1, 4, and through the points 1′2′3′4′ let fall pers. cutting these three par. lines in the points 1, 2, 3, 4, 5, 6; join these points by straight lines

as shown, and a true drawing of the section of the prism as required will result.

For the third condition of the problem:

Let XX be the edge view of the cutting plane and conceive that part of the prism to the right of XX to be removed.

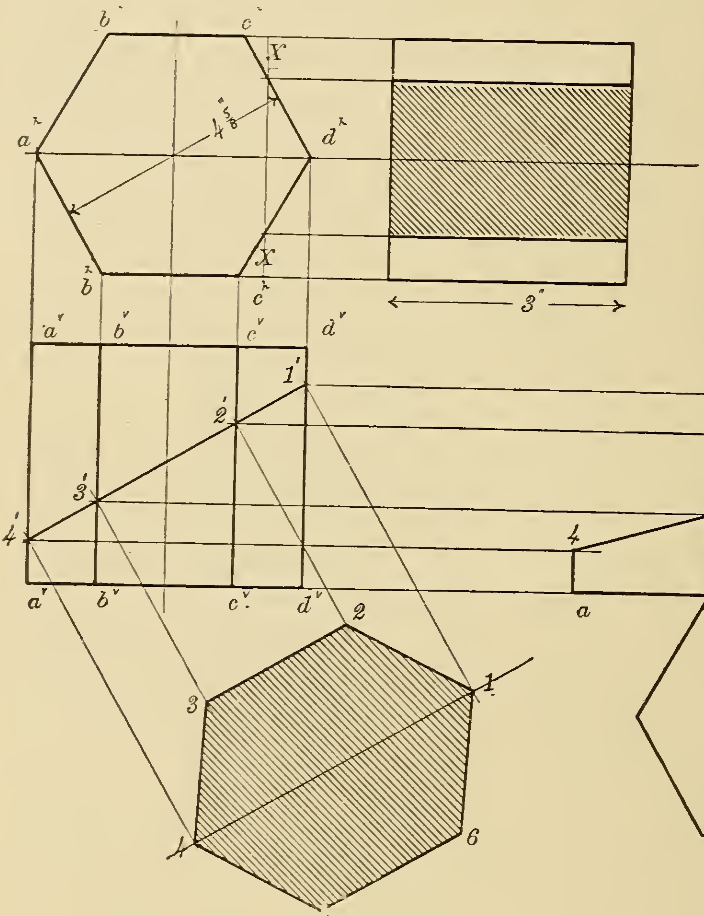


FIG. 125.

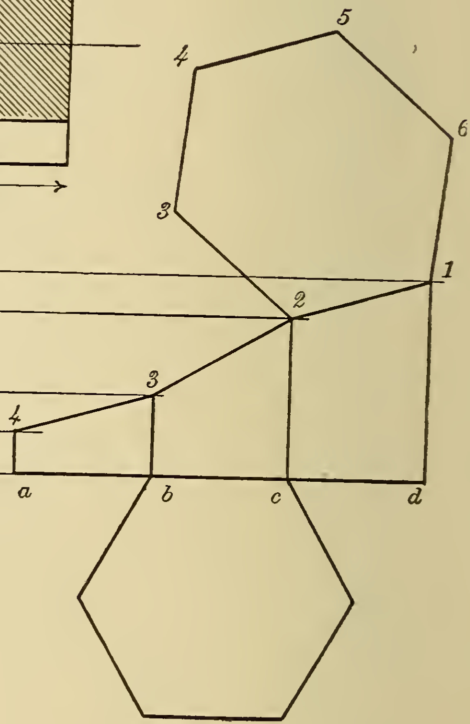


FIG. 126.

From the hor. proj. of the prism draw a right-hand elevation or profile proj., and through the points XX draw the lines enclosing the section, and hatch-line it as shown.

PROB. 13.—To draw the development of the lower part of the prism in the elevation of the last problem.

To the right of the elevation in Fig. 125, prolong the base-line indefinitely and lay off upon it the distances *ab*, *bc*, *cd*, etc., Fig. 126, each equal in length to a side of the hex. At these points erect pers., and through the points $1'2'3'4'$ draw hor. lines intersecting the pers. in 4, 3, 2, 1, etc. At *bc* draw the hex. $a^h b^h b^h, c^h c^h, d^h$ of the last prob. for the base, and at 1, 2 draw the section 1, 2, 3, 4, 5, 6 for the top.

PROB. 14, FIG. 127.—To draw the projs. of a right cylinder 3″ diam. and 3″ long. (1) When its axis is per. to the H.P. (2) Draw the true form of a section of the cylinder, when cut by a plane per. to the V.P. making an angle of 30° with the H.P. (3) Draw a development of the upper part of the cyl.

For the plan of the first condition, describe the circle 1′, 2′, etc., with a radius = $1\frac{1}{2}''$ and from it project the elevation, which will be a square of 3″ sides.

For the second condition: Let 1, 7 be the trace of the cutting plane, making the point 7, $\frac{1}{2}''$ from the top of the cyl. Divide the circle into 12 equal parts and let fall pers. through these divisions to the line of section, cutting it in the points 1, 2, 3, 4, etc. Parallel to the line of section 1, 7 draw $1''7''$ at a convenient distance from it, and through the points 1, 2, 3, 4, etc., draw pers. to 1, 7, intersecting and extending beyond $1''7''$. Lay off on these pers. the distances $6''8'' = 6'8'$, and $5''9'' = 5'9'$, etc., and through the points 2″, 3″, 4″, etc., describe the ellipse.

For the development: In line with the top of the elevation draw the line $g'g''$ equal in length to the circumference of the circle, and divide it into 12 equal parts a', b', etc., a'', b'', etc. Through these points drop pers. and through the points

1, 2, 3, etc., draw hors. intersecting the pers. in the points 1, 2, 3, etc., and through these points draw a curve.

Tangent to any point on the straight line draw a 3″ circle for the top of the cyl. and tangent to any suitable point on the curve transfer a tracing of the ellipse.

PROB. 15, FIG. 128.—Draw the projections of a right cone 7″ high, with a base 6″ in diam., pierced by a right cyl. 2″ in

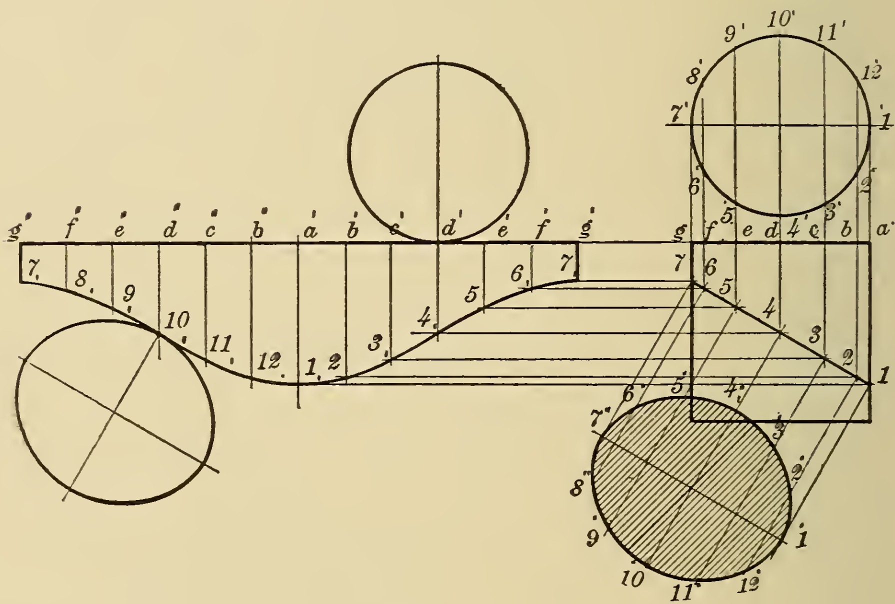


FIG. 127.

diam. and 5″ long their axes intersecting at right angles 3″ above the base of the cone and par. to V.P. Draw first the plan of the cone with a radius = 3″.

At a convenient distance below the plan draw the elevation to the dimensions required.

3″ above the base of the cone draw the center line of the cyl. *CD*, and about it construct the elevation of the cyl., which will appear as a rectangle 2″ wide and 2½″ each side of the axis of the cone. The half only appears in the figure.

To project the curves of intersection between the cyl. and cone in the plan and elevation: Draw to the right of the cyl. on the same center line a semicircle with a radius equal that of the cyl. Divide the semicircle into any number of parts,

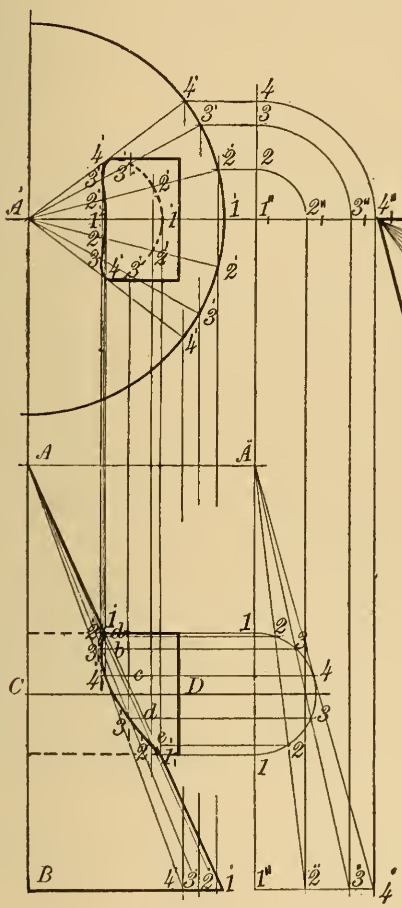


FIG. 128.

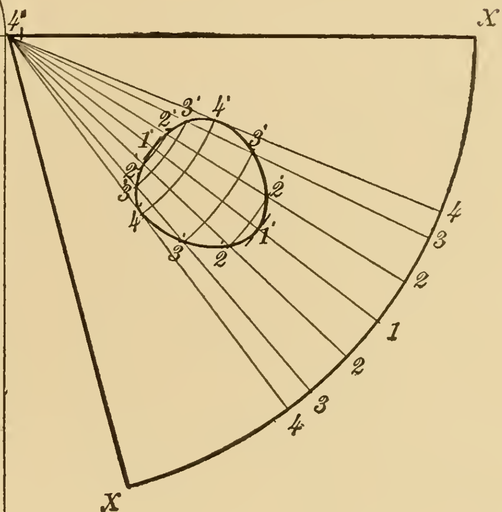


FIG. 129.

as 1, 2, 3, 4, etc. Through 1, 1 draw the per. $A''\ 1''$ equal in length to the height of the cone, and through A'' draw the line $A''4''$ tangent to the semicircle at the point 4, and through the other divisions of the semicircle draw lines from A'' to the line $1''4''$, meeting it in the points $3''2''$.

From all points on the line $1''4''$, viz., $1''2''3''4''$, erect

pers. to the center line of the plan, cutting it in the points $1_1''2_1''3_1''4_1''$, and with $1_1''$ as the center draw the arcs $2_1''$–2, $3_1''$–3, $4_1''$–4 above the center line of the plan, and through the points 2, 3, 4 draw hors. to intersect the circle of the plan in the points $2'3'4'$, and lay off the same distances on the other side of the center line of the plan in same order, viz., $2'3'4'$. Through each of these points on the circumference of the circle of the plan draw radii to its center A', and through the same points also in the plan let fall pers. to the base of the elevation of the cone, cutting it in the points $2'3'4'$; and from the apex A of the elevation of the cone draw lines to the points $2'3'4'$ on the base. Hor. lines drawn through the points of division 2, 3, 4 on the semicircle will intersect the elements A–$2'$, A–$3'$, A–$4'$ of the cone in the points $2'3'4'$; these will be points in the elevation of the curve of intersection between the cylinder and the cone.

The plan of the curve is found by erecting pers. through the points in the elevation of the curve to intersect the radial lines of the plan in correspondingly figured points, through which trace the curve as shown. Repeat for the other half of the curve.

PROB. 16, FIG. 129.—To draw the development of the half cone, showing the hole penetrated by the cyl.

With center $4_1''$, Fig. 129, and element $A1'$ of the cone, Fig. 128, as radius, describe an arc equal in length to the semicircle of the base of the cone. Bisect it in the line $4_1''1$, and on each side of the point 1 lay off the distances 2, 3, 4, equal to the divisions of the arc in the plan Fig. 128, and from these points draw lines to $4''$, the center of the arc. Then with radii A–a, b, c, d, e, respectively, on the elevation Fig. 128,

and center $4_1''$ draw arcs intersecting the lines drawn from the arc XX to its center $4_1''$. Through the points of intersection draw the curve as shown by Fig. 129.

PROB. 17, FIG. 130.—To draw the development of the half of a truncated cone, given the plan and elevation of the cone.

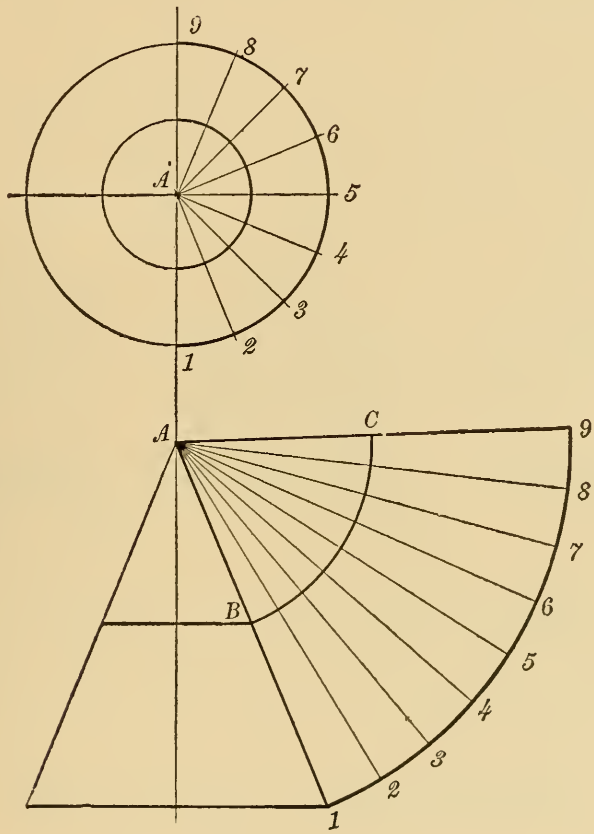


FIG. 130.

Divide the semicircle of the plan into any number of parts, then with A as center and A 1 as radius, draw an arc and lay off upon it from the point 1 the divisions of the semicircle from 1 to 9, draw $9A$. Then with center A and radius AB draw the arc BC. $1BC9$ is the development of the half of the cone approximately.

PROB. 18, FIG. 131.—To draw the curve of intersection of a small cyl. with a larger. To the left of the center-line of Fig. 131 is a half cross-section, and to the right a half elevation of the two cyls.

Draw the half plan of the small cyl., which will be a semicircle, and divide it into any convenient number of parts, say 12.

From each of these divisions drop pers.

On the half cross-section these pers. intersect the circumference of the large cyl. in the points 1′, 2′, etc. Through

FIG. 134.

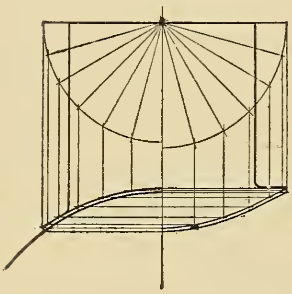


FIG. 133.

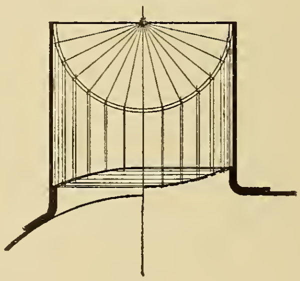
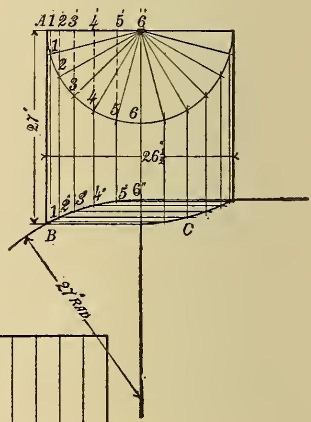


FIG. 131.



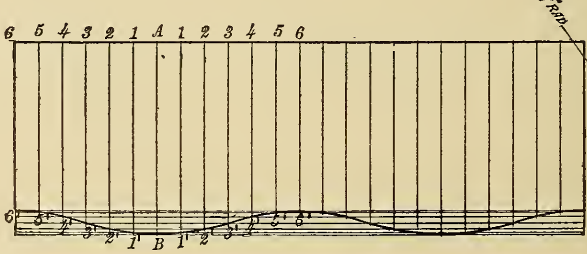


FIG. 132.

these points draw hors. to intersect in corresponding points the pers. on the half elevation. Through the latter points draw the curve of intersection *C*.

PROB. 19.—To draw the development of the smaller cyl. of the last prob.

Draw a rectangle, Fig. 132, with sides equal to the circum-

ference and length of the cyl. respectively, and divide it into 24 equal parts.

Make *AB*, 1 1′, 3 3′, etc., Fig. 132, equal to *AB*, 1′1″, 2′2″, 3′3″, etc., Fig. 131, and draw the developed curve of intersection.

PROB. 20.—To draw the orthographic projections of a cylindrical dome riveted to a cylindrical boiler of given dimensions.

Let the dimensions of the dome and boiler be: dome $26\frac{1}{2}''$ diam. $\times$ $27''$ high, boiler $54''$ diam., plates $\frac{1}{2}''$ thick.

Apply to the solution of this problem the principles explained in Prob. No. 18, Fig. 131.

When your drawings are completed, compare them with Figs. 133 and 134, which are the projections required in the problem.

Letter or number the drawing and be prepared to explain how the different projections were found.

PROB. 21.—To draw the development of the top gusset-sheets of a locomotive wagon-top boiler of given dimensions.

First draw the longitudinal cross-section of the boiler to the dimensions given by Fig. 135, using the scale of $1'' =$ 1 ft.

Then at any convenient point on your paper draw a straight line, and upon it lay off a distance *AB* $35\frac{1}{2}''$ long $=$ the straight part of the top of the gusset-sheet *G*, Fig. 135. With center *A* and a radius $= 27\frac{7}{8}''$ (the largest radius of the gusset) $+ 6''$ (the distance from the center of the boiler to the center of the gusset *C*, Fig. 135) $= 33\frac{7}{8}''$, draw arc 1.

With center *B* and a radius $= 26\frac{7}{8}''$ (the smallest radius of the gusset) draw arc 2. Tangent to these arcs draw the

straight line 1, 2 extended, and through the points *A* and draw lines 1, *A* and 2, *B* per. to 1, 2.

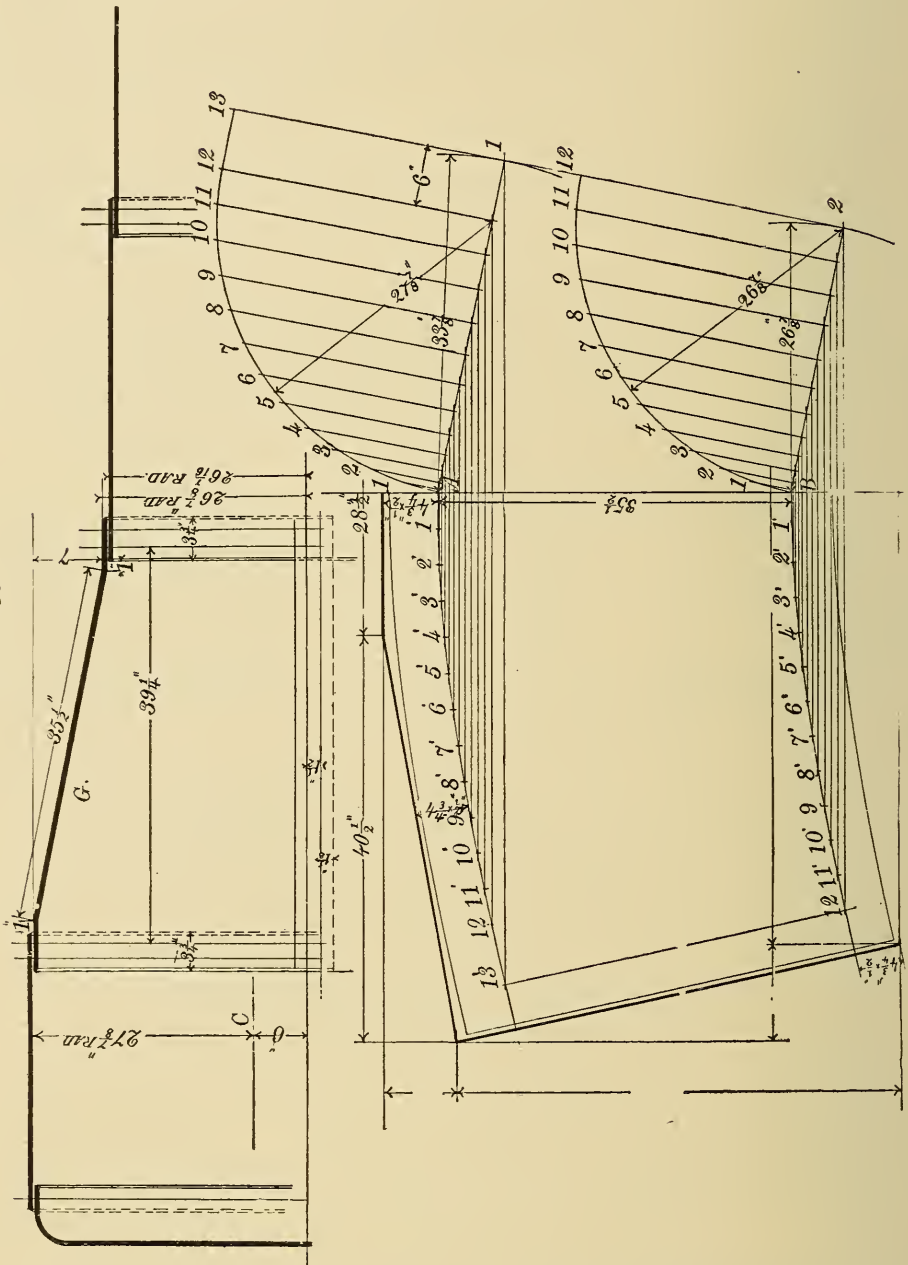


Fig. 135.

Fig. 136.

Take a point on the per. 1, 2, 6″ from the point 1 as a center and through the point *A* draw an arc with a radius $= 27\frac{7}{8}''$.

With point 2 as a center and $2B$ as a radius ($26\frac{7}{8}''$) draw an arc through B to meet the line 1, 2.

Divide both arcs into any number of parts, say 12, and through these divisions draw lines per. to and intersecting $1A$ and $2B$ respectively. Through these intersections draw indefinite hors. and on these hors. step off the length of the arcs, with a distance = one of the 12 divisions as follows:

On the first hors. lay off the length of the arc $A1'$ and $B1'$ $= A1$ and $B1$ respectively. Then from $1'$ lay off the same distance to $2'$ on the second hors. etc. Through these points draw curves $A13'$ and $B12'$. Join points $12'$ and $13'$ with a straight line Then $AB12$, 13 will be the developed half of the straight part of the gusset.

On the two ends or front and back of the gusset we have now to add $1''$ for clearance + $3\frac{3}{4}''$ for lap + $\frac{1}{2}''$ allowance for truing up the plates, total = $5\frac{1}{4}''$. And to the sides $2\frac{5}{8}''$ for lap + $\frac{1}{2}''$ allowance for truing up, total = $3\frac{1}{8}''$.

The outline of the developed sheet may now be drawn to include these dimensions with as little waste as possible, as shown by Fig. 136. Extreme accuracy is necessary in making this drawing, as the final dimensions must be found by measurement.

PROB. 22.—To draw the projections of a V-threaded screw and its nut of $3''$ diam. and $\frac{3}{4}''$ pitch.

Begin by drawing the center line C, Fig. 137, and lay off on each side of it the radius of the screw $1\frac{1}{2}''$. Draw AB and $6D$. Draw $A6$ the bottom of the screw, and on AB step off the pitch = $\frac{3}{4}''$, beginning at the point A.

On line $6D$ from the point 6 lay off a distance = half the pitch = $\frac{3}{8}''$, because when the point of the thread has com-

pleted half a revolution it will have risen perpendicularly a distance = half the pitch, viz., $\frac{3}{8}''$.

Then from the point $6''$ on $6D$ step off as many pitches as may be desired. From the points of the threads just found,

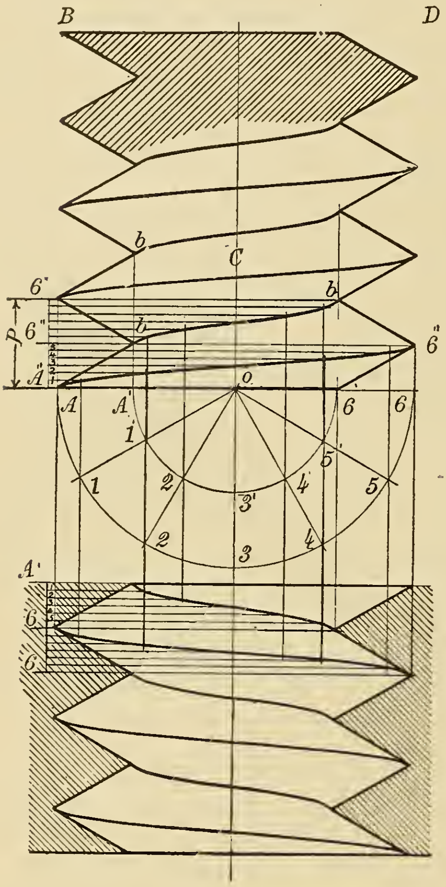


FIG. 137.

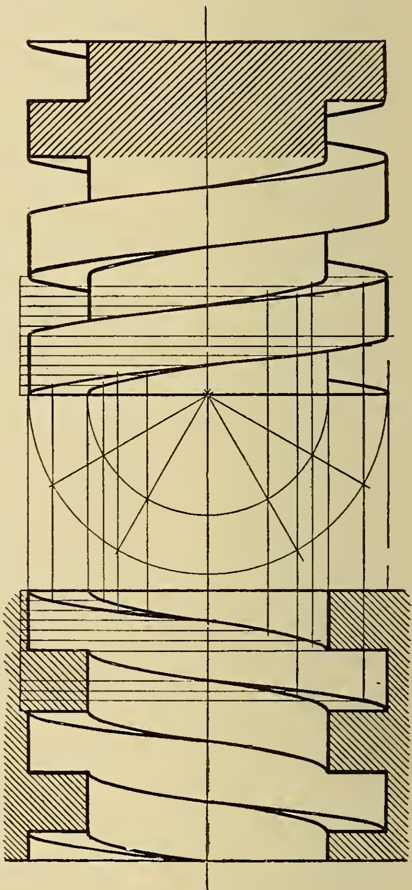


FIG. 138.

draw with the 30° triangle and T-square the V of the threads intersecting at the points *b* . . *b* . . the bottom of the threads.

At the point *O* on line *A*6 draw two semicircles with radii || the top and bottom of the thread respectively. Divide these into any number of equal parts and also the pitch *P* into the same number of equal parts. Through these divisions draw hors. and pers. intersecting each other in the points as

shown by Fig. 137, which shows an elevation partly in section and a section of a nut to fit the screw. Through the points of intersection draw the curves of the helices shown, using No. 3 of the "Sibley College Set" of Irregular Curves.

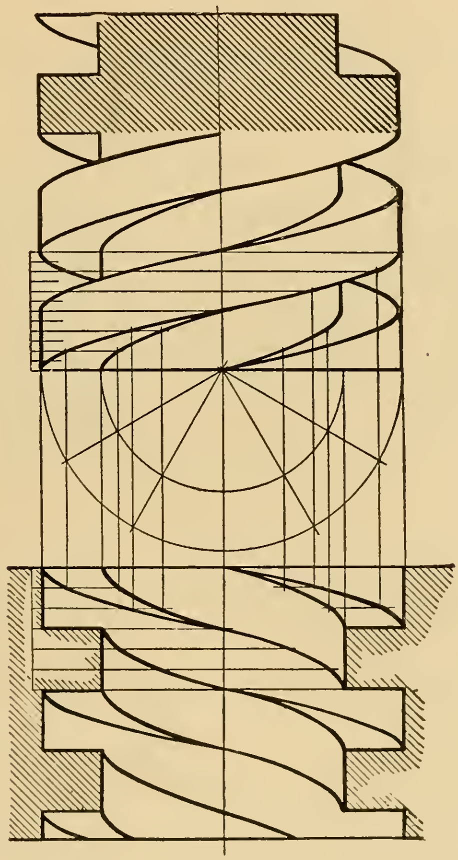


FIG. 139.

PROB. 22.—To draw the proj. of a square-threaded screw 3″ diam. and 1″ pitch and also a section of its nut.

The method of construction is the same as for the last problem, and is illustrated by Fig. 138.

PROB. 22.—To draw the projections of a square double threaded screw of 3″ diam. and 2″ pitch, and also a section of its nut.

The solution of this problem is shown by Fig. 139, and further explanation should be unnecessary.

PROB. 23.—To draw the curve of intersection that is formed by a plane cutting an irregular surface of revolution.

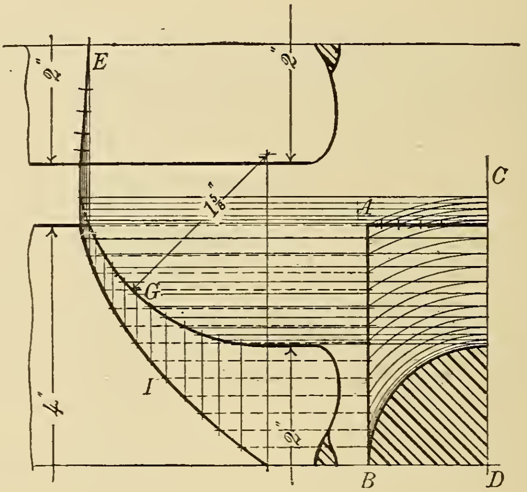


FIG. 140.

Figs. 140, 141, and 142 show examples of engine connecting rod ends where the curve *I* is formed by the inter-

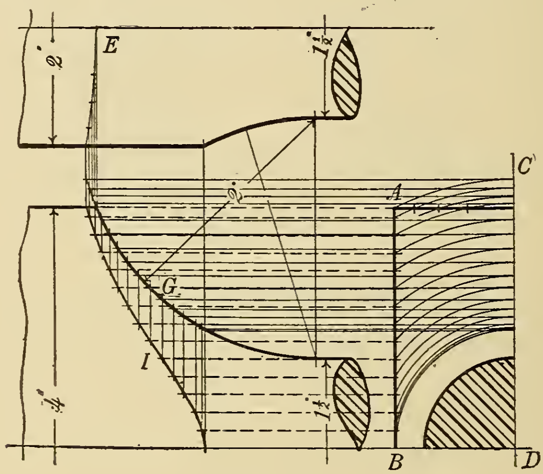


FIG. 141.

section of the flat stub end with the surface of revolution of the turned part of the rod.

The method of finding the curves of intersection are so plainly shown by the figures that a detailed explanation is deemed unnecessary.

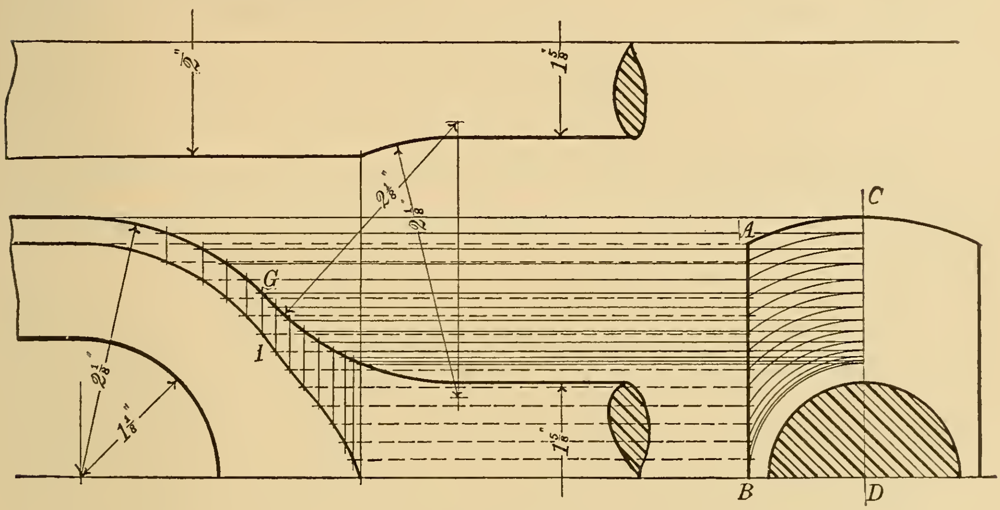


FIG. 142.

SHADE LINES, SHADES AND SHADOWS.

Shade Lines are quite generally used on engineering working drawings; they give a relieving appearance to the projecting parts, improve the looks of the drawing and make it easier to read, and are quickly and easily applied.

The *Shading* of the curved surfaces of machine parts is sometimes practiced on specially finished drawings, but on working drawings most employers will not allow shading because it takes too much time, and is not essential to a quick and correct reading of a drawing, especially if a system of shade lines is used.

Some of the principles of shade lines and shading are given below, with a few problems illustrating their commonest applications.

The *shadows* which opaque objects cast on the planes of

projection or on other objects are seldom or never shown on a working drawing, and as the students in Sibley College are taught this subject in a course on Descriptive Geometry, it is omitted here.

CONVENTIONS.

The Source of Light is considered to be at an infinite distance from the object, therefore the Rays of Light will be represented by parallel lines.

The Source of Light is considered to be fixed, and the Point of Sight situated in front of the object and at an infinite distance from it, so that the *Visual Rays* are parallel to one another and per. to the plane of projection.

Shade Lines divide illuminated surfaces from dark surfaces.

Dark surfaces are not necessarily to be defined by those surfaces which are darkened by the shadow cast by another part of the object, but by reason of their location in relation to the rays of light.

It is the general practice to shade-line the different projections of an object as if each projection was in the same plane, e.g., suppose a cube, Fig. 143, situated in space in the third angle, the point of sight in front of it, and the direction of the rays of light coinciding with the diagonal of the cube, as shown by Fig. 144. Then the edges $a^v b^v$, $b^v c^v$ will be shade lines, because they are the edges which separate the illuminated faces (the faces upon which fall the rays of light) from the shaded faces, as shown by Fig. 144.

Now the source of light being fixed, let the point of sight remain in the same position, and conceive the object to be revolved through the angle of 90° about a hor. axis so that a

plan at the top of the object is shown above the elevation, and as the projected rays of light falling in the direction of the diagonal of a cube make angles of 45° with the hor., then with the use of the 45° triangle we can easily determine that the lower and right-hand edges of the plan as well as of the elevation should be shade lines.

This practice then will be followed in this work, viz.:

Shade lines shall be applied to all *projections* of an object,

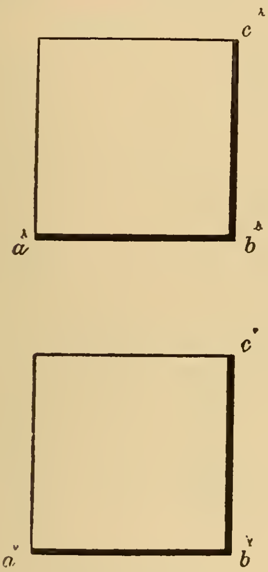


FIG. 143.

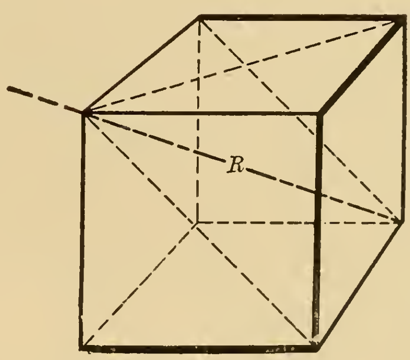


FIG. 144.

considering the rays of light to fall upon each of them, from the same direction.

Shade lines should have a *width* equal to 3 times that of the other outlines. *Broken lines* should never be shade lines.

The outlines of *surfaces of revolution* should not be shade lines. The shade-lined figures which follow will assist in illustrating the above principles; they should be studied until understood.

SHADES.

The *shade* of an object is that part of the surface from which light is excluded by the object.

The *line of shade* is the line separating the shaded from the illuminated part of an object, and is found where the rays of light are tangent to the object.

Brilliant Points.—" When a ray of light falls upon a surface which turns it from its course and gives it another direction, the ray is said to be reflected. The ray as it falls upon the surface is called the incident ray, and after it leaves the surface the reflected ray. The point at which the reflection takes places is called the *point of incidence.*

" It is ascertained by experiment—

" (*a*) That the plane of the incident and reflected rays is always normal to the surface at the point of incidence;

" (*b*) That at the point of incidence the incident and reflected rays make equal angles with the tangent plane or normal line to the surface.

" If therefore we suppose a single luminous point and the light emanating from it to fall upon any surface and to be reflected to the eye, the point at which the reflection takes place is called the brilliant point. The brilliant point of a surface is, then, the point at which a ray of light and a line drawn to the eye make equal angles with the tangent plane or normal line—the plane of the two lines being normal to the surface."
—Davies: *Shades and Shadows.*

Considering the rays of light to be parallel and the point of sight at an infinite distance, the brilliant point on the surface of a *sphere* is found as follows: Let A^vC^v and A^hC^h, Fig.

145, be a ray of light and A^vA^h a visual ray. Bisect the angles contained between the ray of light and the visual ray as follows: Revolve A^vC^v about the axis A^v until it becomes parallel to the hor. plane at $A^vC_1^v$. At C_1^v erect a per. to intersect a hor. through C^h at C_1^h join $C_1^hL^h$ (L may be any convenient

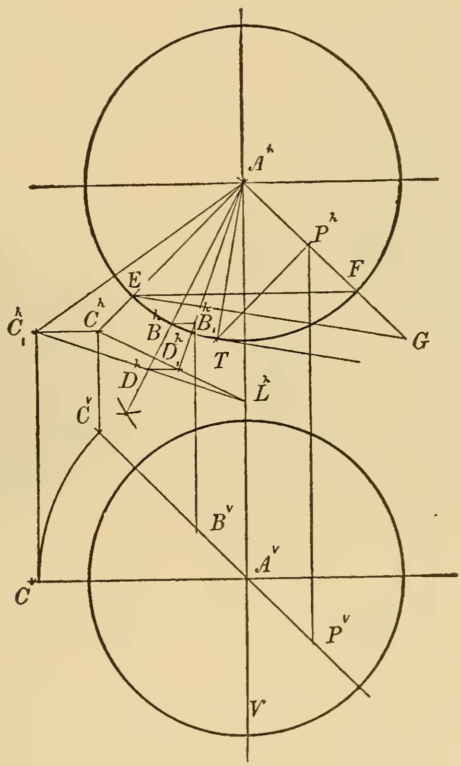


FIG. 145.

point on the line of vision), bisect the angle $L^hA^hC_1^h$ with the line A^hD^h. Join C^hL^h and through the point D^h, draw a hor. cutting C^hL^h at D_1^h, then $A^hD_1^h$ is the hor. projection of the bisecting line. A plane drawn per. to this bisecting line and tangent to 'the sphere touches the surface at the points $B^vB_1^h$ where the bisecting lines pierce it. Therefore B^vB^h are the two projections of the brilliant point.

The point of shade can be found as follows:

Draw A^hG, Fig. 145, making an angle of 45° with a hor. Join the points E and F with a straight line EF. Lay off on A^hG a distance equal to EF, and join EG. Parallel to EG

Fig. 146.

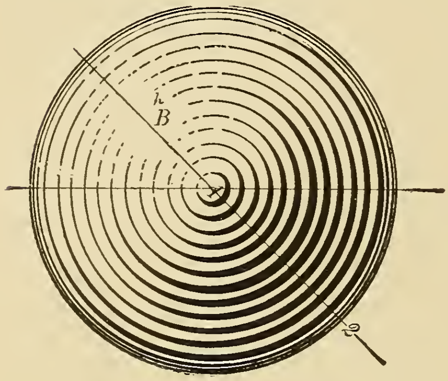
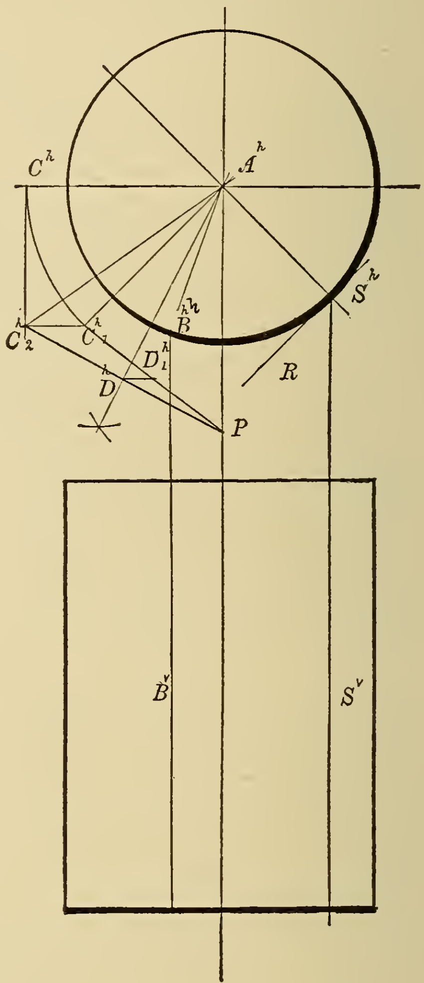


Fig. 147.



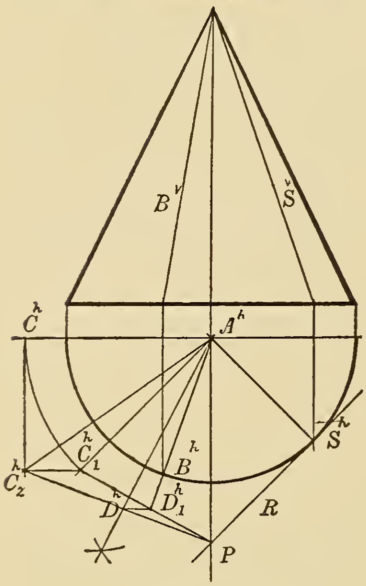


Fig. 148.

draw a tangent to the sphere at the point T. Through T draw TP^h per. to A^hG. From the point P^h drop a per. to P^v. P^v is the point of shade.

Prob. 24.—To shade the elevation of a sphere with graded arcs of circles.

First find the brilliant point and the point of shade, and divide the radius 1, 2 into a suitable number of equal parts, and draw arcs of circles as shown by Fig. 146, grading them by moving the center a short distance on each side of the center of the sphere on the line B^h2 and varying the length of the radii to obtain a grade of line that will give a proper shade to the sphere. It is desirable to use a horn center to protect the center of the figure.

Fig. 149 shows the stippling method of shading the sphere.

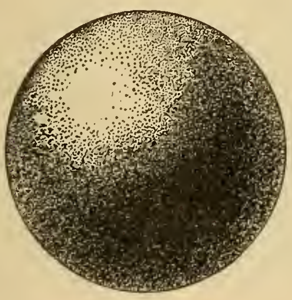


FIG. 149.

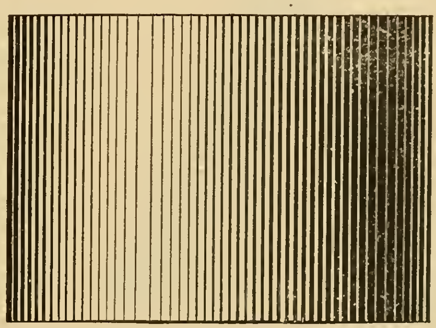


FIG. 150.

PROB. 25.—To shade a right cylinder with graded right lines.

Find the line of light B^v by the same method used to find the brilliant point on the sphere, except that the line of light is projected from the point B^h where the bisection line A^hD cuts the circle of the cylinder.

The line of shade is found where a plane of rays is tangent to the cyl. at S^v and S^h.

Fig. 150 shows how the shading lines are graded from the line of shade to the line of light.

It will be noticed that the lines grow a little narrower to the right of the line of shade on Fig. 150; this shows where

the reflection of the rays of light partly illumine the outline of the cylinder.

PROB. 26, FIG. 148.—To shade a right cone with graded right lines tapering toward the apex of the cone.

Find the elements of light and shade as shown by Fig. 148, and draw the shading-lines as shown by Fig. 151, grading their width toward the light and tapering them toward the apex of the cone.

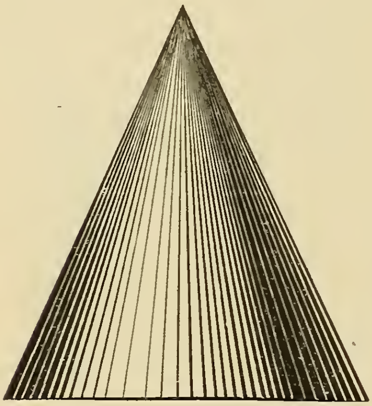


FIG. 151.

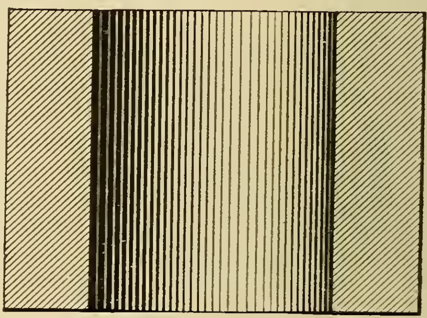


FIG. 152.

The mixed appearance of the lines near the apex of the cone on Fig. 151 can usually be avoided by letting each line dry before drawing another through it, or as some draftsmen do, stop the lines just before they touch.

PROB. 27.—To shade the concave surface of a section of a hollow cylinder.

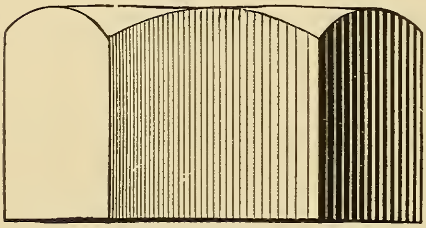


FIG. 153.

Find the element of light and grade the shading lines from it to both edges as shown by Fig. 152.

Fig. 153 shows a conventional method of shading a hexagonal nut.

SHADOWS.

Let *R*, Fig. 154, be the direction of the rays of light and *C* an opaque body between the source of light and a

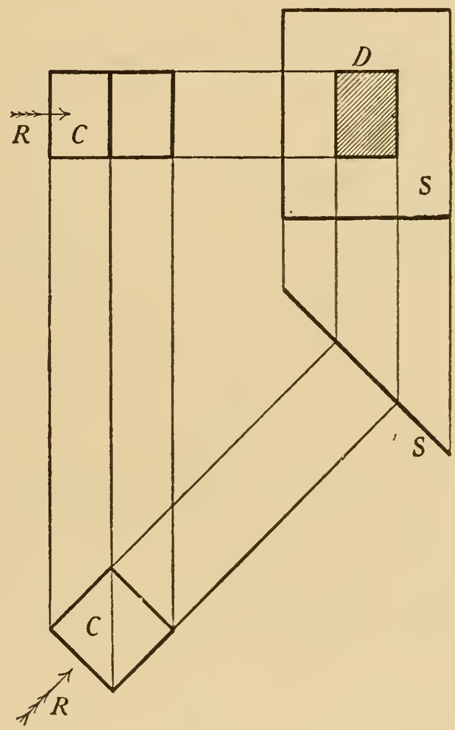


FIG. 154.

surface *S*. The body *C* will prevent the rays from passing in that direction, and its outline will be projected at *D* on the surface *S*. *D* is the *shadow* of *C*.

The line which divides the illuminated portion of the surface *S* from the shadow *D* is called the *line of shadow*.

Shadow of a Point.—If a line is drawn through a point in space in a direction opposite to the source of light, the point in which this line pierces the plane of projection is the shadow of the point on that plane.

To find the shadow on the H.P. of a point in space in the first dihedral angle:

Let A, Fig. 155, be the point in space, and R the direction of the ray of light; then A_1^H is the shadow of the point A on H.P., and $A^H A_1^H$ is the hor. proj. and $A^V A_1^V$ the

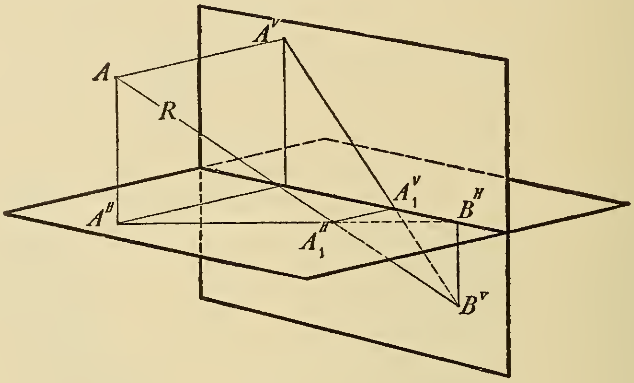


FIG. 155.

vert. proj. of R. B^V is the point where R pierces V when prolonged below H.P., and B^H is its hor. proj. in the G.L. The projections of R would then be $A^V B^V$ and $A^H B^H$.

The shadow of a point in V may be found in a similar manner.

Shadows of Right Lines.—The shadow of a right line on a plane may be determined by finding the shadows of two of its points and joining these by a right line; e.g., the shadow of the line AB, Fig. 156, on H.P. is found as follows:

Through the points $A^V B^V$ draw the rays $A^V A_1^V$ and $B^V B_1^V$ to intersect the plane of projection in G.L. in the points A_1^V and B_1^V; from these points drop perpendiculars to meet rays drawn through A^H and B^H in the points A_1^H and B_1^H. A line drawn from A_1^H to B_1^H is the shadow of AB on H.P.

If a righ tline is parallel to the plane of projection its shadow will be parallel to the line itself.

If a line coincides with a ray of light, its shadow on any surface will be a point.

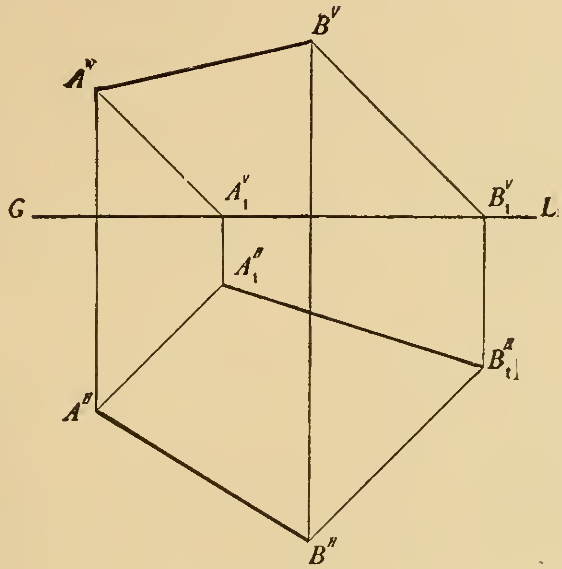


FIG. 156.

PROB. 28.—*To find the shadow of a right line on V.P. and H.P.*

Let AB, Fig. 157, be the given line. Find the shadows

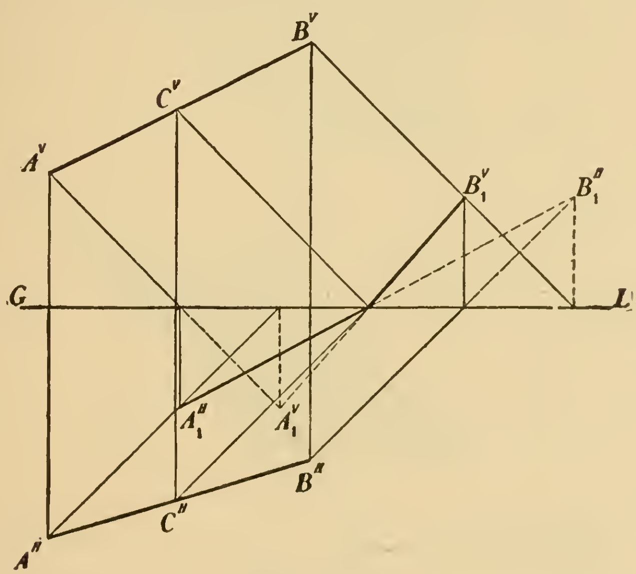


FIG. 157.

of the points A and B by passing rays through each of their projections to make angles of 45° with G.L. The shadow of A^H on H.P. is found at A_1^H, and that of B^H at B_1^H, where the rays through these points intersect the H.P. The shadow of A^V on V.P. is found at A_1^V and that of B^V at B_1^V, where the rays through these points intersect V.P. Join A_1^H and B_1^H with a straight line and we have the shadow of AB on H.P., and the shadow on V.P. is found in the same way by joining with a straight line the points A_1^V and B_1^V.

That part of the shadow which falls on V.P. below G.L., and on H.P. above G.L., is called the *secondary* shadow, because it makes a second intersection, i.e., it is conceived to have passed through V.P. and made an intersection with H.P. behind V.P. With the use of the secondary shadow problems like this are easier of solution.

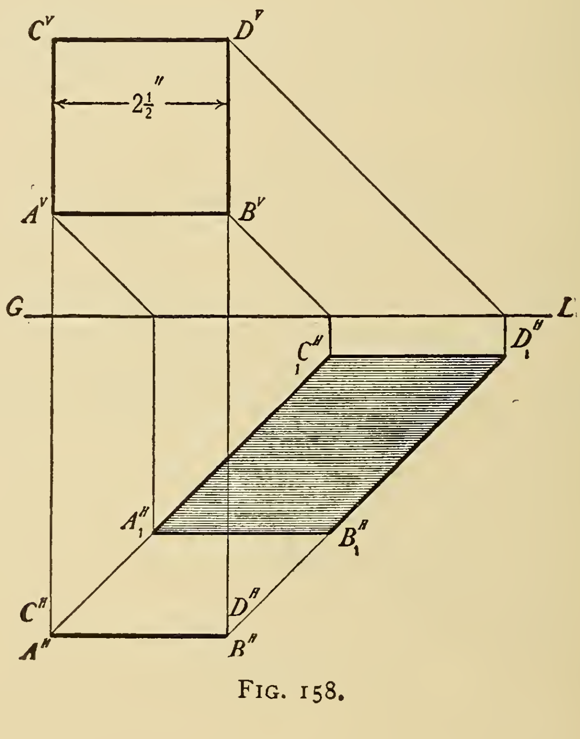


FIG. 158.

PROB. 29.—*ABCD, Fig. 158, is a square plate parallel to V.P.; find its shadow on H.P.*

Through the points A^V, B^V, D^V, and A^HC^H, B^HD^H, draw rays making the angle of 45° (or any other angle which may be adopted) with G.L., and determine the shadows of these points as explained in Fig. 155. They will be found in the points $A_1^HB_1^H$, C_1^H, D_1^H. Join these points with right lines and they will form the line of shadow of the square plate on H.P.

PROB. 30.—*To find the shadow of a cube on V.P. with one face in V.P. and the other faces parallel or perpendicular to H.P.*

Fig. 159 shows the cube in the given position. The line

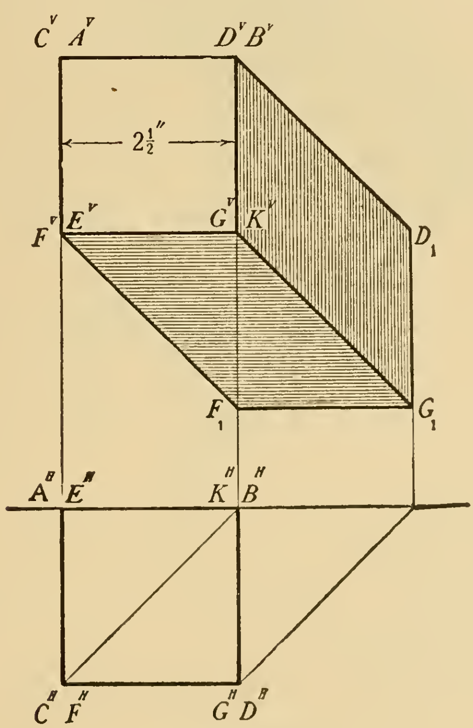


FIG. 159.

of shade is composed of edges EF, FG, GD, DB, and the edges AE and AB in V.P. which coincide with their shadows.

The shadow of EF is $E^V F_1$, of FG is $F_1 G_1$, of GD is $G_1 D_1$, of DB is $D_1 B^V$. The shadows of the edges AE and AB coincide with the lines. These shadows are found by the same rules used for finding the shadows of a line in Prob. 28. The line of shadow is $B^V D_1 G_1 F_1 F^V E^V A^V D^V$. The visible line of shadow is $B^V D_1 G_1 F_1 E^V C^V D^V$.

PROB. 31.—*To find the shadow of a rectangular abacus on the face of a rectangular pillar.*

Assume the hor. and vert. projs. of the abacus and pillar to be as shown in Fig. 160.

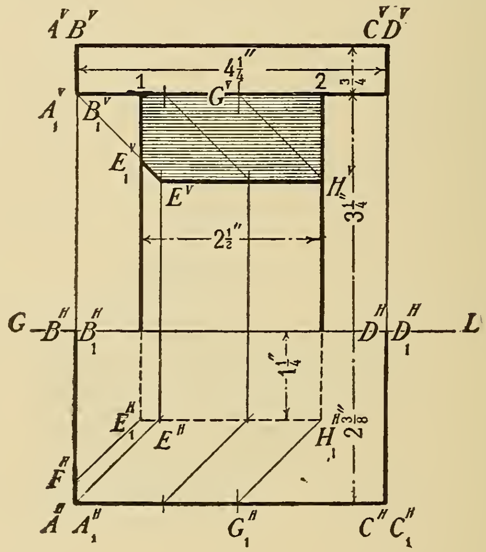


FIG. 160.

The line of shade of the abacus is seen to be the edges $A_1^H B_1^H$ and $A_1^H C_1^H$. The plane of rays through edge $A_1^H B_1^H$ is per. to V.P., and the line $A_1^V E^V$ is its vert. proj. or trace; its hor. trace is $A_1^H E^H$. The shadow on the left side face, is vertically projected in the point E_1^V where the plane of rays intersects that face. The ray through the point A_1^H pierces the front face in the point E^H, which is the shadow of A_1^H,

and $E_1^H E^H$, $E_1^V e^V$ is the shadow of the part $F^H A_1^H$ on this face.

The line $A_1^H C_1^H$ is parallel to the front face, therefore its shadow on it will be parallel to itself and pass through E.

The visible line of shadow is now found to be 1 $E_1^V E^V H^V$ 2 1.

PROB. 32.—*Construct the shade of an upright hex. prism and its shadow on both planes.*

Fig. 161 shows the given prism with its line of shade

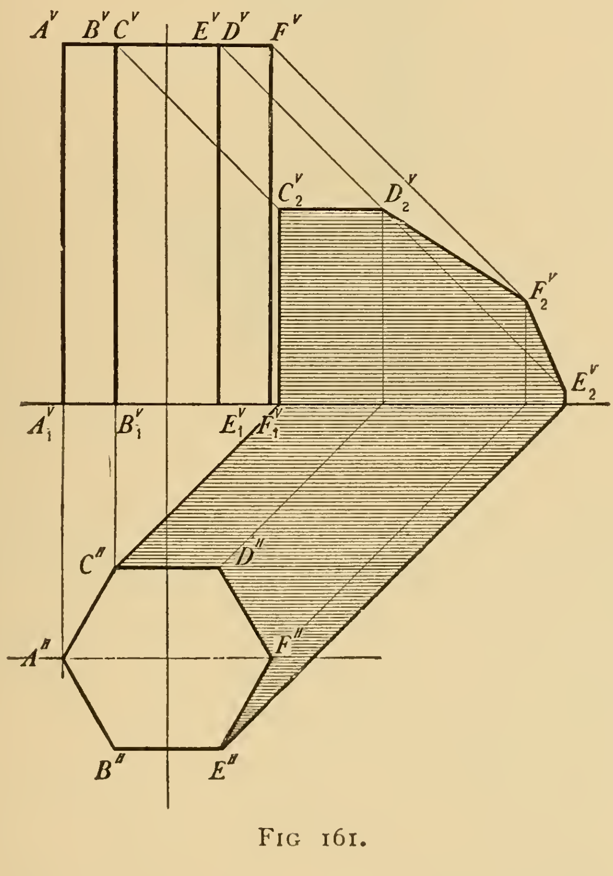


FIG 161.

$A_1^V B_1^V E_1^V D^V F^V$ on the vert. proj., $C^H D^H F^H E^H$ on the hor. proj., and its shadow on both planes.

PROB. 33.—*Given a circular plate parallel to one coordinate plane; construct its shadow on the other plane.*

Let $A^VB^VC^VD^V$ and A^HC^H, Fig. 162, be the projections of the circular plate.

Circumscribe a square E^VG^V about the circle; its shadow on H.P. will be the parallelogram A^HG^H, and the shadows of the points $A^VB^VC^VD^V$ are projected in the points

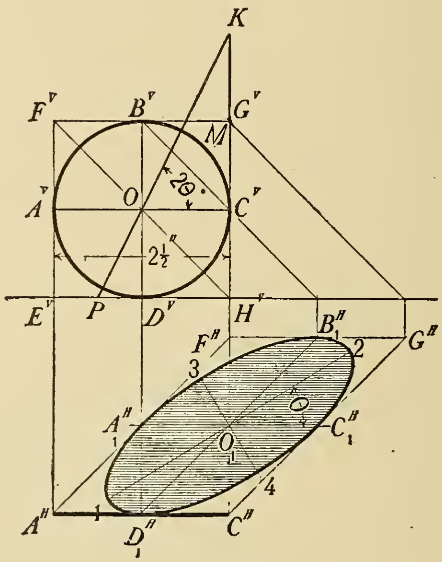


FIG. 162.

$A_1^HB_1^HC_1^HD_1^H$. The shadow of the inscribed circle is an ellipse tangent to the parallelogram at the points $A_1^HB_1^HC_1^HD_1^H$, with $B_1^HD_1^H$ and $A_1^HC_1^H$ as conjugate diameters.

The position and length of the axes of the ellipse of shadow may be found as follows:

Erect a perpendicular at the point C^V making G^VK^V equal to radius of the circle· draw KOP; then KP is equal to the major and MK to the minor axis, and angle θ is twice the angle of the transverse axis with the horizontal conjugate diam.; i.e., KP is equal to 1, 2, MK to 3, 4, and 2, $O_1C_1^H$, or angle θ, is equal to half KOC^V.

PROB. 34.—*Find the shade of a cylindrical column and abacus, and the shadow of the abacus on the column.*

Let $A^VB^VC^V$ and $A^HB^HC^H$, Fig. 163, be the projections of the abacus, $D^HE^HF^H$ and $D^HD^VG^VF^H$ the projections of the column.

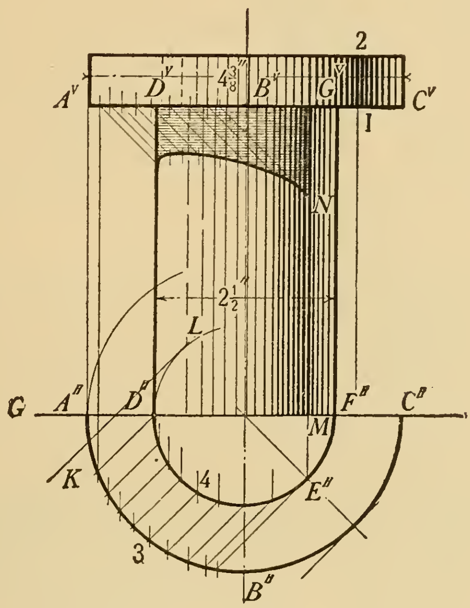


FIG. 163.

The line of shade on the column is found by passing two planes of rays tangent to the column perpendicular to H.P. and parallel to the hor. proj. of the ray of light. KL and E^H are the traces of these planes tangent to the column at the points L, and E^H and MN the visible line of deepest shade on the cylindrical column.

The deepest line of shade 1, 2 on the abacus is found in the same way.

The line of shadow on the column of that portion of the lower circumference of the abacus which is toward the source of light is found by passing vertical planes of rays, as 3, 4, to

determine any number of points in the line, and joining these points by a line as shown in Fig. 163.

PROB. 35.—*Find the shade of an oblique cone and its shadow on H.P.*

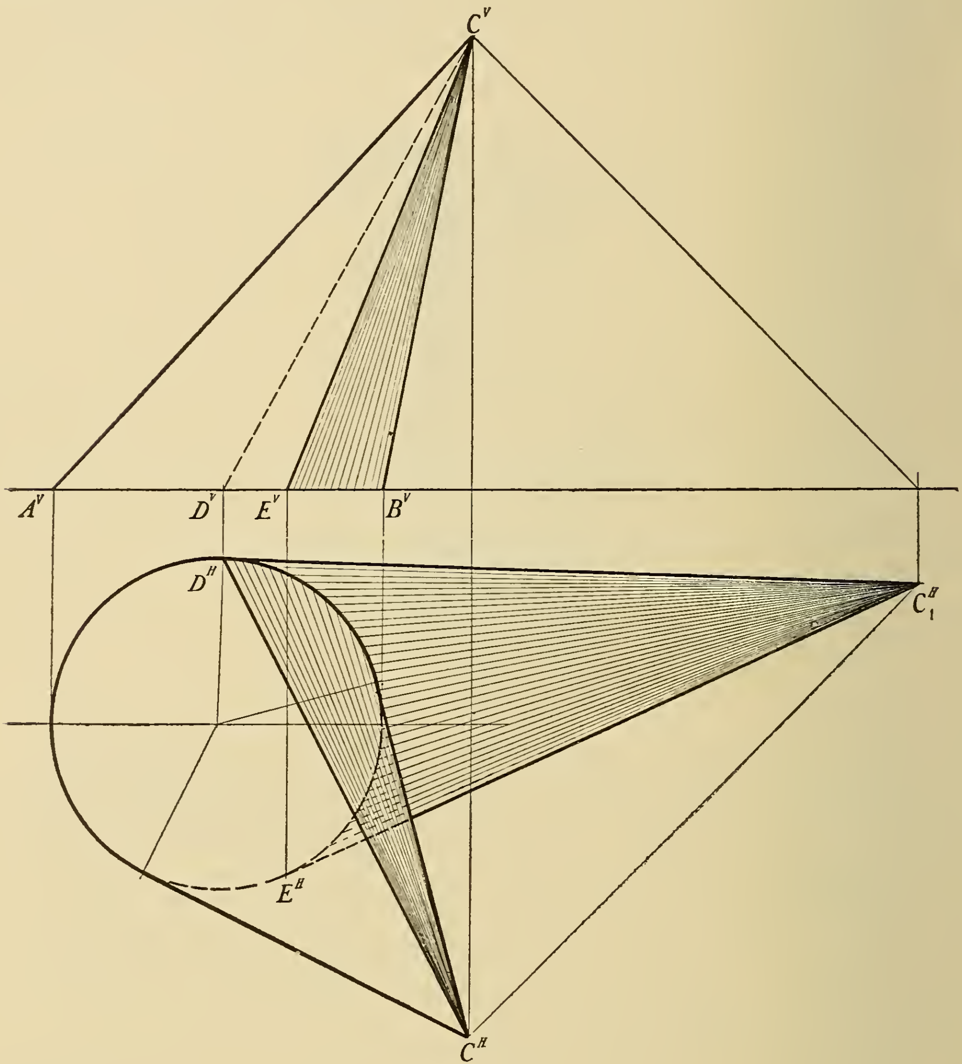


FIG. 164.

Take the cone as given in Fig. 164. Pass two planes of rays tangent to the cone; their elements of contact will be the deepest lines of shade. To determine the elements of contact draw a ray through C^V; C_1^H is its hor. trace. From

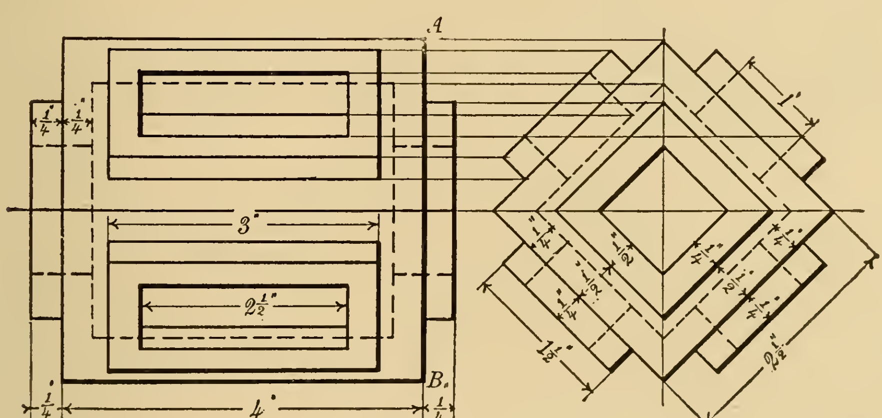
C_1^H draw lines tangent to the base at D and E; the lines of contact are CE and CD, and ECD is the line of shade.

The visible line of shade on H.P. is $E^H D^H$, and on V.P. it is $C^V E^V$. The shadow on H.P. is $E^H C_1^H D^H$.

PROB. 36.—To draw a front and end elevation of a rectangular hollow box with a rectangular block on each face, each block to have a rectangular opening, and all to be properly shade-lined and drawn to the dimensions given on Fig. 165.

Draw the hor. center line first, and then the vertical center line of the end view. About these center lines on the end el-

FIG. 165.



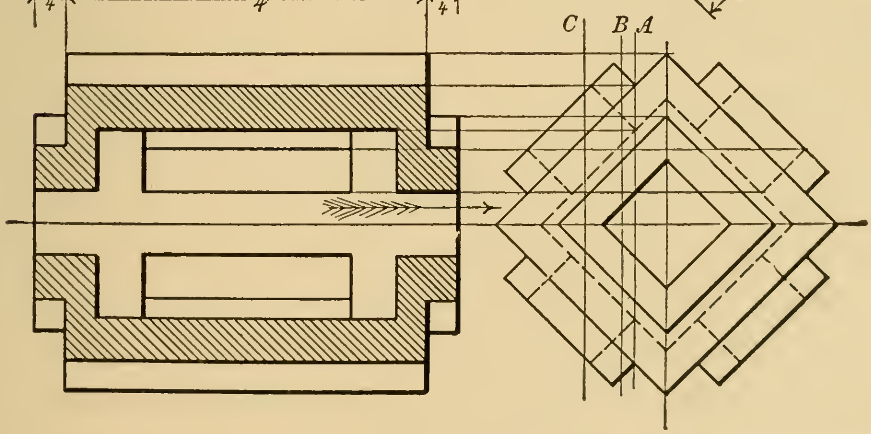


FIG. 166.

evation construct the squares shown and erect the edges of the blocks. Next draw the hidden lines indicating the thickness

of the walls of the box and the openings through the blocks, measuring the sizes carefully to the given dimensions.

Draw the front elevation by projecting lines from the various points on the end elevation, and assuming the position of the line *AB* measure off the lengths of the hor. lines and erect their vert. boundaries as shown by the figure.

PROB. 37.—Given the end elevation of the last prob., cut by three planes *A*, *B* and *C*, Fig. 166. Draw the projections of these sections when the part to the left of the cutting plane has been removed, and what remains is viewed in the direction of the arrow, remembering that all the visual rays are parallel.

These drawings and all that may follow are to be properly shade-lined in accordance with the principles given above.

ISOMETRICAL DRAWING.

In orthographic projection it is necessary to a correct understanding of an object to have at least two views, a front and end elevation, or an elevation and plan, and sometimes even three views are required.

Isometric drawing on the other hand shows an object completely with only one view. It is a very convenient system for the workshop. Davidson in his *Projection* calls it the "Perspective of the Workshop." It is more useful than perspective for a working drawing, because, as its name implies ("equal measures") it can be made to any scale and measured like an orthographic drawing. It is, however, mainly employed to represent small objects, or large objects drawn to a small scale, whose main lines are at right angles to each other.

The principles of isometrical drawing are founded on a cube resting on its lower front corner, 1, Fig. 167, and its base

elevated so that its diagonal AB is parallel to the horizontal plane. Then if the cube is rotated on the corner 1 until the diagonal AB is at right angles to the vert. plane, i.e., through an angle of 90°, the front elevation will appear as shown at 1, 2, 3, 4, Fig. 167, a regular hexagon.

Now we know that in a regular hexagon, as shown by Fig. 167, the lines $1A$, $A3$, etc., are all equal, and are easily drawn

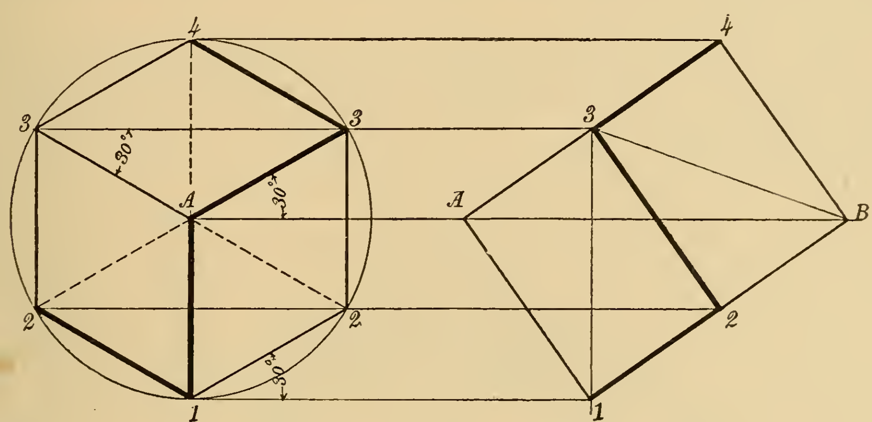


FIG. 167.

with the 30° × 60° triangle. But although these lines and faces appear to be equal, yet, being inclined to the plane of projection, they are shorter than they would actually be on the cube itself. However, since they all bear the same proportion to the original sizes, they can all be measured with the same scale.

We will now describe the method of making an isometrical scale.

Draw the half of a square with sides = $2\frac{1}{2}''$, Fig. 168. These two sides will make the angle of 45° with the horizontal. Now the sides of the corresponding isometrical square, we have seen, make the angle of 30° with the horizontal, so we will

draw 1 4, 3 4, making angles of 30° with 1, 3. The difference then between the angle 2, 1, 3 and the angle 4, 1, 3 is 15°, and the proportion of the isometrical projection to the actual object is as the length of the line 3, 2 to the line 3, 4. And if the line 3, 2 be divided into any number of equal parts, and lines be drawn through these divisions par. to 2, 4 to cut the line 3, 4 in corresponding divisions, these will divide 3, 4 proportionately to 3, 2.

Now if the divisions on 3, 2 be taken to represent feet and those on 3, 4 to represent 2 feet, then 3, 4 would be an isometrical scale of $\frac{1}{2}$.

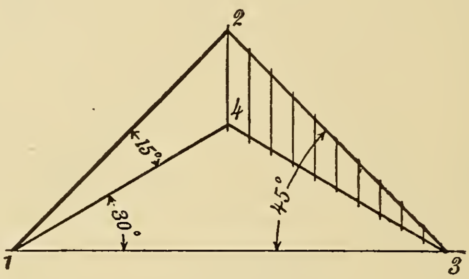


FIG. 168.

Since isometrical drawings may be made to any scale, we may make the isometrical lines of the object = their true size. This is a common practice and precludes the need of a special isometrical scale.

The Direction of the Rays of Light.—The projection of a ray of light in isometrical drawing will make the angle of 30° with the horizontal as shown by the line 3, 2 on the front elevation of the hex., Fig. 167. And the *shade lines* will be applied as in ordinary projection.

PROB. 38.—To make the isometrical drawing of a two-armed cross standing on a square pedestal.

Begin by drawing a center line *AB*, Fig. 169, and from the point *A* draw *AC* and *AD*, making an angle of 30° with the horizontal. Measure from *A* on the center line *AB* a distance = $\frac{5}{16}''$, and draw lines par. to *AC*, *AD*; make *AC* and *AD* $2\frac{5}{8}''$ long and erect a perpendicular at *D* and *C*, completing the two front sides of the base, etc.

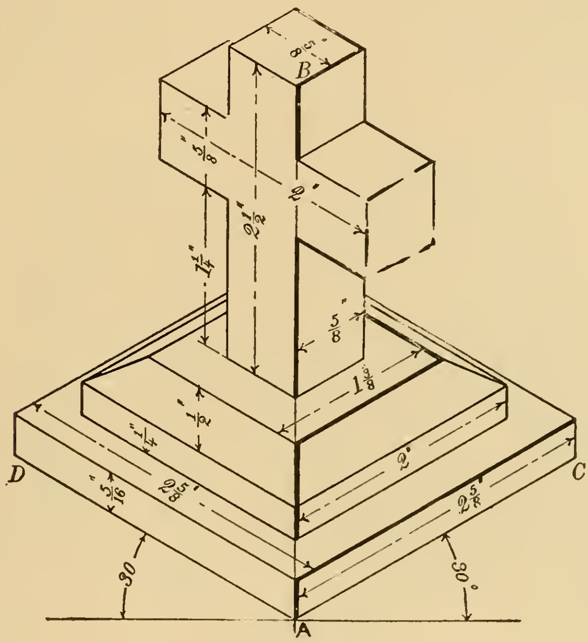


FIG. 169.

PROB. 39.—To make the isometrical drawing of a hollow cube, with square block on each face and a square hole through each block, to dimensions given on Fig. 170.

As before, first draw a center line, and make an isometrical drawing of a $2\frac{1}{2}''$ cube, and upon each face of it build the blocks with the square holes in them, exactly as shown in Fig. 170.

PROB. 40.—To project an isometrical circle.

The circle is enclosed in a square, as shown by Fig. 171.

Draw the circle with a radius = 2″ and describe the square 1, 2, 3, 4 about it.

Draw the diagonals 1, 2, 3, 4 and the diameters 5, 6, 7, 8 at right angles to each other.

Now from the points 1 and 2 draw lines 1*A*, 1*B* and 2*A*, 2*B*, making angles of 30° with the hor. diagonal 1, 2. And

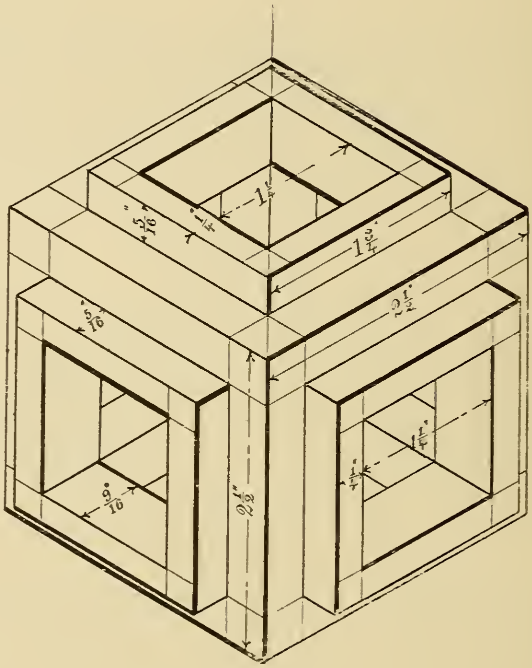


FIG. 170.

through the center *O* draw *CD* and *EF* at right angles to the isometrical square.

The points *CD*, *EF*, and *GH* will be points in the curve of the projected isometrical circle, which will be an ellipse.

The ellipse may be drawn sufficiently accurate as follows:

With center *B* and radius *BC* describe the arc *CF* and extend it a little beyond the points *C* and *F*, and with center *A* and same rad. describe a similar arc, then with a rad. which

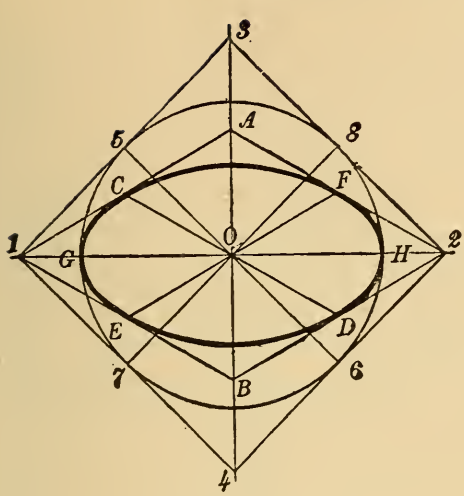


FIG. 171.

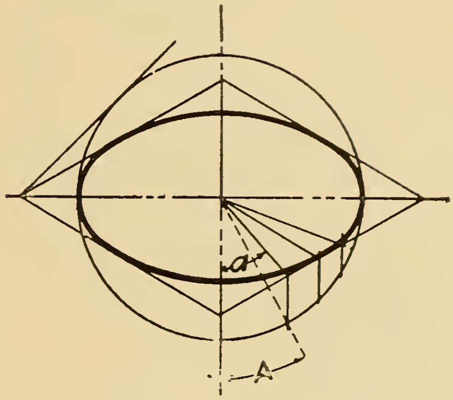


FIG. 172.

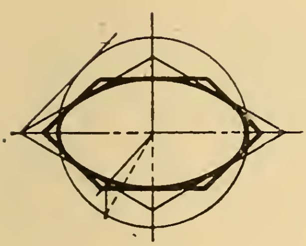


FIG. 173.

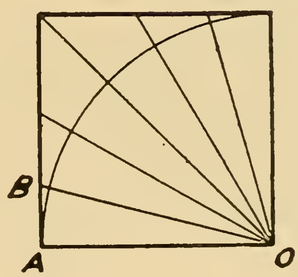


FIG. 174.

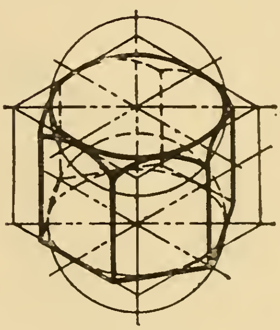


FIG. 175.

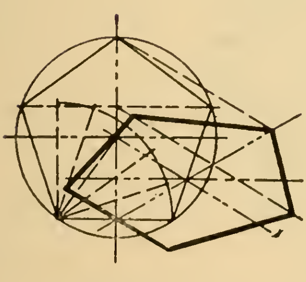


FIG. 176.

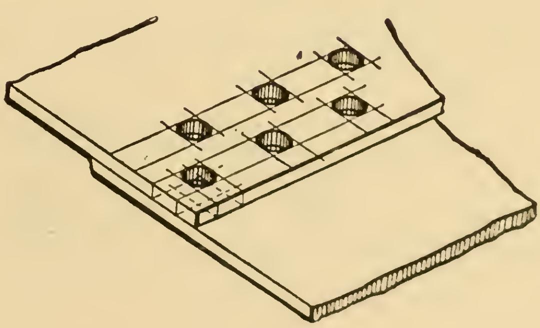


FIG. 177.

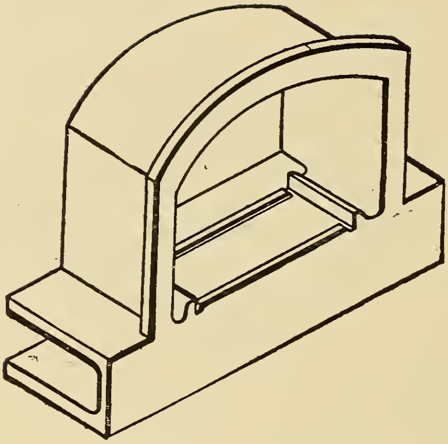


Fig. 178.

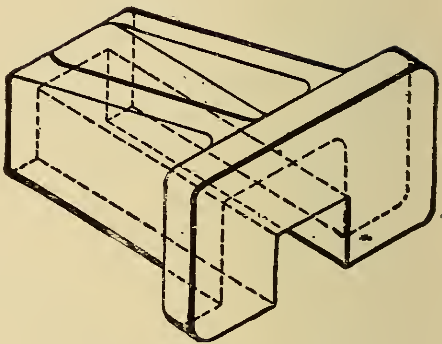


Fig. 179.

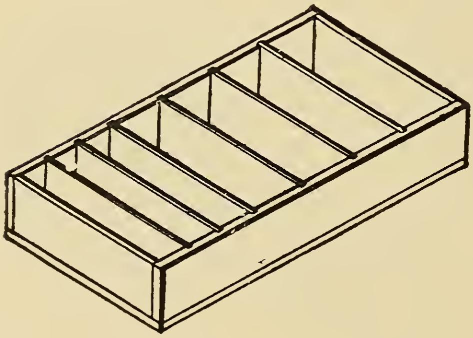


Fig. 180.

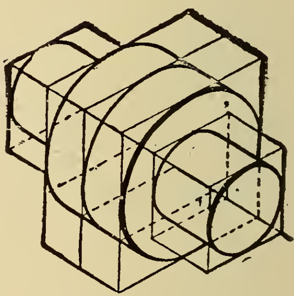


Fig. 181.

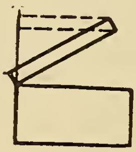


Fig. 182.

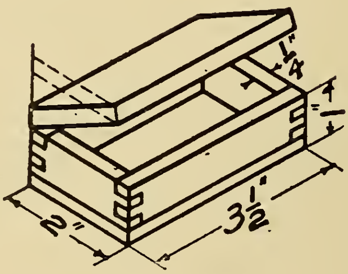


Fig. 183.

may readily be found by trial, draw arcs through the points *G* and *H* and tangent to the two arcs already described.

PROB. 41.—To lay off an angle from a corner of the isometrical cube.

Construct an orthographic square of any convenient size as shown in Fig. 174, and draw the required angle *AOB*. From the corner of the isometrical cube where the angle is to be drawn lay off along the side a distance equal to *OA* of the orthographic square and erect a perpendicular at *A*. Step off the distance *AB* and draw *OB* the angle required. Any other angle may be drawn in similar manner.

Figs. 177, 178, 179, 180, 181, and 184 are for practice in the application of the preceding principles, and at least one

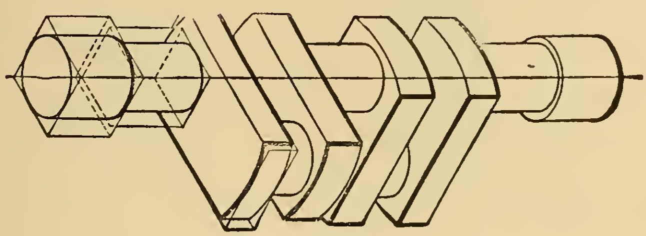


FIG. 184.

of these should be drawn, or it would be better still if the student would attempt to make an isometrical projection of his instrument-box, desk, or any familiar object at hand. These figures may be measured with the $1\frac{1}{2}''$ scale and drawn with the $2''$ scale.

WORKING DRAWINGS.

Working drawings are sometimes made on brown detail-paper in pencil, traced on tracing-paper or cloth, and then blue-printed.

The latter process is accomplished as follows:

The tracing is placed face down on the glass in the printing-frame, and the prepared paper is placed behind it, with the sensitized surface in contact with the back of the tracing.

In printing from a negative the sensitized surface of the prepared paper is placed in contact with the film side of the negative, and the face is exposed to the light.

The blue-print system is almost universal in its application to shop drawings, as evidenced in the report on "Conventions" found at page 165.

A Working Drawing in the hands of an experienced workman is intended to convey to him all the necessary information as to shape, size, material, finish, etc., of a machine or other object that will enable him to properly construct it without any additional instructions. This means that it must have a sufficient number of elevations, sections, and plans to thoroughly explain and describe the object in every particular. And these views should be completely and conveniently dimensioned. The dimensions on the drawing must of course give the sizes to which the object is to be made, without reference to the scale to which it may be drawn. The title of a working drawing should be as brief as possible, and not very large—a neat, plain, free-hand printed letter is best for this purpose.

Finished parts are usually indicated by the letter "f," and if it is all to be finished, then below the title it is customary to write or print "finished all over."

Working drawings may be divided into three general types, viz.: General Plans, Machine Drawings, and Patent Office Drawings.

General Plans consists of foundation drawings, piping drawings, layout drawings, maps, etc.

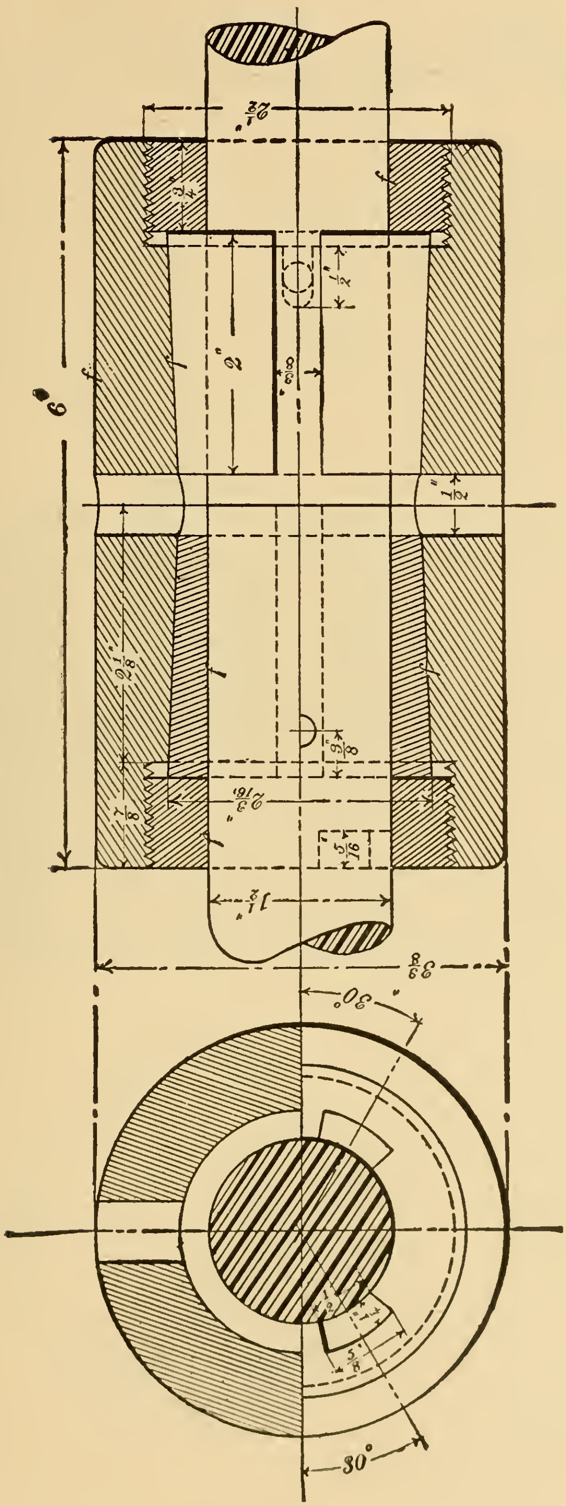


Fig. 185.

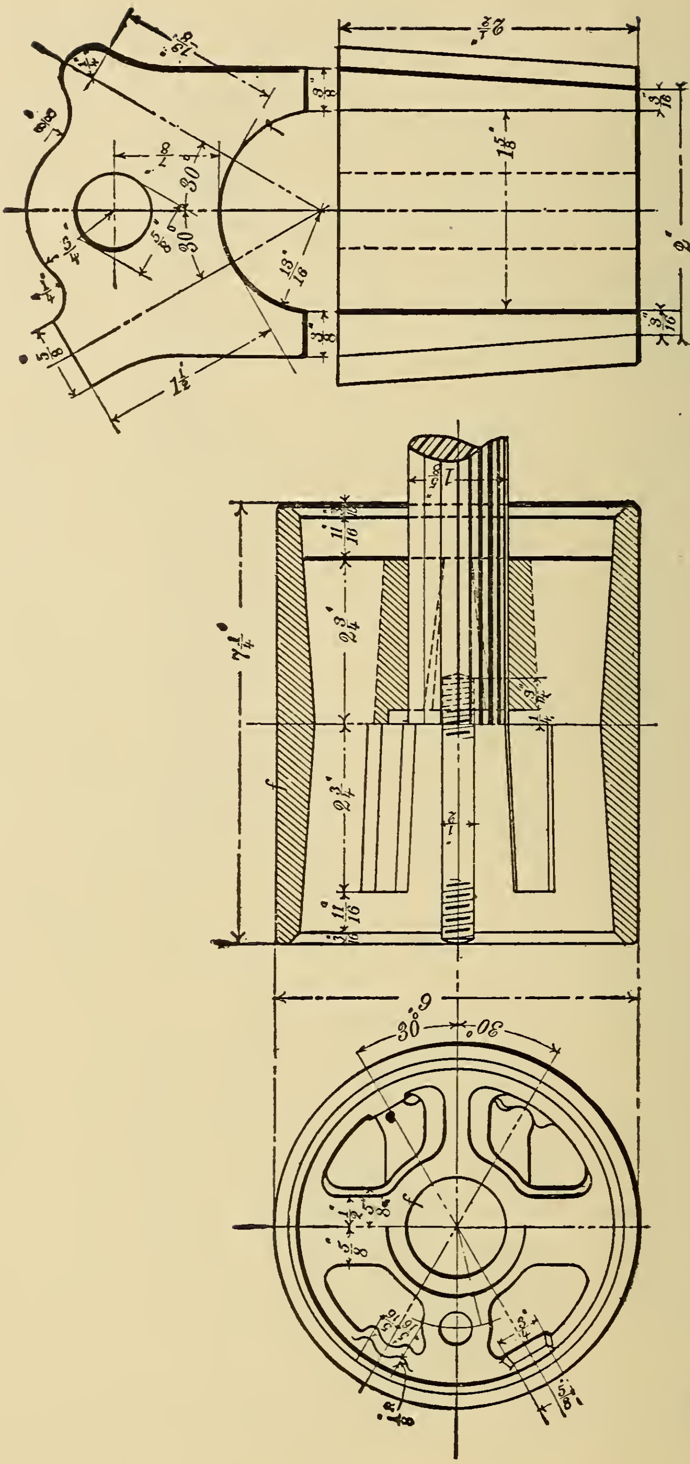


Fig. 186.

Machine drawings include assembly drawings, detail drawings, diagram and kinematic drawings, sketches and scheming sheets.

Patent Office drawings must conform to the requirements of the U. S. Patent Office as published in the "Official Rules of Practice." They are generally made on two sheet white bristol board with black ink. Size of sheet 10″×15″ with a one inch margin all around. From the top border line of one of the narrow edges $1\frac{1}{4}$″ at least should be reserved for title, number and date. The signatures of inventor, attorney, and witnesses must be placed at the bottom of the sheet inside the border line.

Figs. 185 and 186 are Assembly Detail drawings of two shaft couplings, fully dimensioned.

PROB. 42.—Make detail drawing of the Butler's frictional shaft coupling shown in Fig. 185. Scale, full size.

PROB. 43. Make drawings of a Stuart's coupling for $1\frac{5}{8}$″ shaft as shown in Fig. 186. Scale, full size.

These couplings are described in detail in "MECHANICAL DRAWING AND ELEMENTARY MACHINE DESIGN," by John S. and D. Reid, John Wiley & Sons, New York.

COURSE I.

PROBLEMS IN MECHANICAL DRAWING

INCLUDING

LETTERING, GEOMETRICAL DRAWING, ORTHOGRAPHIC PROJECTION, DEVELOPMENTS, INTERSECTIONS, ISOMETRICAL DRAWING AND WORKING DRAWING.

COURSE I.

MECHANICAL DRAWING.

MINIMUM NUMBER OF PLATES AND MAXIMUM NUMBER OF HOURS ALLOWED TO COMPLETE EACH DIVISION OF THE WORK.

FIRST SEMESTER.

PLATES 1 TO 6 inclusive, consisting of free-hand lettering must be completed and handed in on or before Friday, Oct. 16, 1908. (26 hours.)

All lettering on regular period will then stop and the work on Geometrical Drawing will begin.

PLATES 7 TO 10 inclusive, must be completed and handed in on or before Wednesday, Nov. 25. (22 hours.)

Works on Orthographic Drawing will begin on Monday, Nov. 30.

PLATES 11 TO 14 inclusive, must be completed and handed in on or before Friday, January 29, 1909. (28 hours.)

Students failing to finish any of the divisions of the work within the time allowed, by reason of excused absence, may make arrangements with the instructor to work in one or more extra periods.

Students doing more than the required number of plates in the given time will receive a higher mark, other things being equal.

END OF FIRST SEMESTER.

Note.—Registered freshmen conditioned in Mechanical Drawing will be required to complete satisfactorily the following plates of this course: 1 to 6 inclusive, 10, 11, 12, 14, 17, 19, 21, and 22, according to the directions given in the text. Conditioned students must work at least six hours per week. When the above plates are finished, work on Machine Drawing may be commenced.

SECOND SEMESTER.

Orthographic Projection continued, beginning Feb. 2, 1909.

PLATES 15 AND 16 must be completed and handed in not later than Friday March 5, 1909. (18 hours.)

March 8, work on Developments begins.

PLATES 17 AND 18 must be finished and handed in not later than Friday, April 2, 1909. (16 hours.)

April 5, work on Intersections begins.

PLATES 19 AND 20 must be finished on or before Friday, April 23, 1909. (12 hours.)

April 26, work on Isometrical Drawing begins.

PLATE 21 must be completed by Friday, May 7, 1909. (8 hours.)

May 10, work begins on the last required plate of the course consisting of a "Working Drawing."

PLATE 22 must be completed and handed in not later than Friday, May 21. (8 hours.)

Students failing to complete any of the divisions of the course satisfactorily within the time allowed (for excusable reasons),

may make arrangements with the Instructor to work in one or more extra periods.

Students doing more than the required number of plates in the given time will receive a higher mark, other things being equal.

END OF SECOND SEMESTER.

Directions to be Carefully Observed when Commencing Work in Mechanical Drawing.

STUDENTS' CONDUCT IN CLASS.

Students will be expected to give strict attention to their *lettering* or drawing work during the *full* time of each drawing period. Materials and instruments must not be put away until the warning bell rings.

Nothing should be brought to the drawing table that is not needed for the drawing work in hand.

If a student expects to be absent from any regular period he should endeavor to get excused by the Instructor and make arrangements for making up the work.

A student coming late to class should report at *once* to the Instructor, otherwise he will be marked with an unexcused absence. A report from the Instructor concerning the *deportment* of each student in class is expected by the Dean every two months.

When a student is absent from class through an unforseen cause he should at the next regular period fill out an absence blank, giving date and cause of absence, sign it, and hand to Instructor. The work of all absent periods must be made up by arrangement with the Instructor.

PLATE I. *Freehand Lettering,* Fig. 187, page 140.—Use the 4 H pencil sharpened to a long conical point, not too sharp.

PLATE I.

FIG. 187.

Locate the *lower* point of the first guide-line 12 squares from top and 7 squares from left-hand edge of cross-section pad.

Guide-lines should be sketched lightly with a downward stroke and allowed to remain until letters are approved.

PLATE 2.

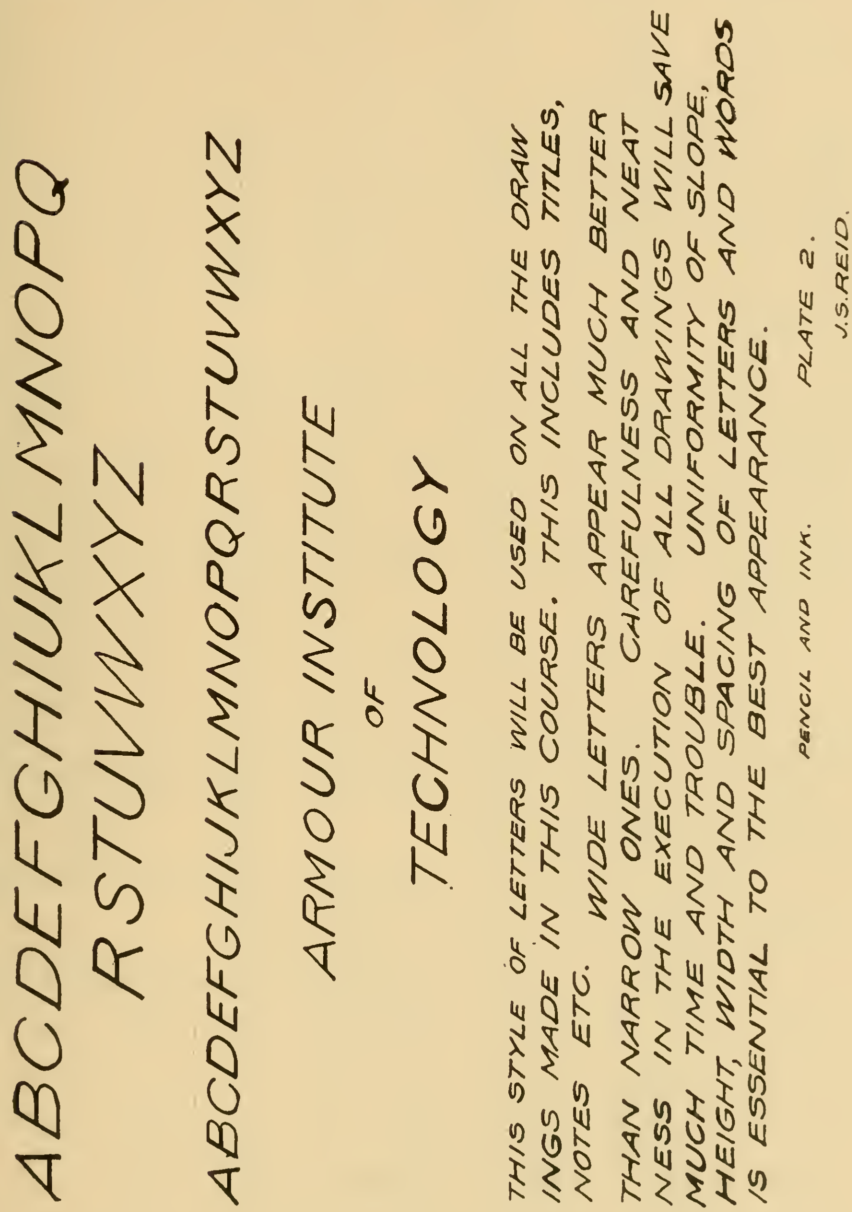


Fig. 188.

After drawing the guide-lines for the *curved* letters, analyze the lines of each curved letter, as given on the *chart* on the blackboard before attempting to draw the curves

on the pad. A very close approximation of the first curved letter as it appears on the *chart* should be obtained before attempting to draw the second curved letter.

Do not copy the letters or figures on pages 140 and 144, the correct form and proportions for all the letters and figures must be obtained by a careful study of the *chart.*

The *work* on all the letters and figures must be *strictly freehand.*

Place at the bottom of each plate at the right-hand corner the following information: *Plate* number, *Section* (days and hours), *Time* taken to finish plate, and *Name,* e.g., MON. and WED., 2–4, *Plate* 1. *Time,* 4 *hours, Name.* The height of these letters should be *one* square high and all capitals

PLATE 2. *Freehand* guide lines must be drawn for all letters and figures higher than one square and allowed to remain until letters are approved.

The same care as to *proportion* and *form* should be observed in lettering this plate as in Plate 1.

Be careful to *balance* letters and numbers on all plates so that the same space will appear from both ends of line to edge of pad.

The small letters should be *extended* in width a little beyond the proportion given for the larger letters.

The *open* letters should be spaced closely together and *words* should have a liberal space between them, say 1½ squares.

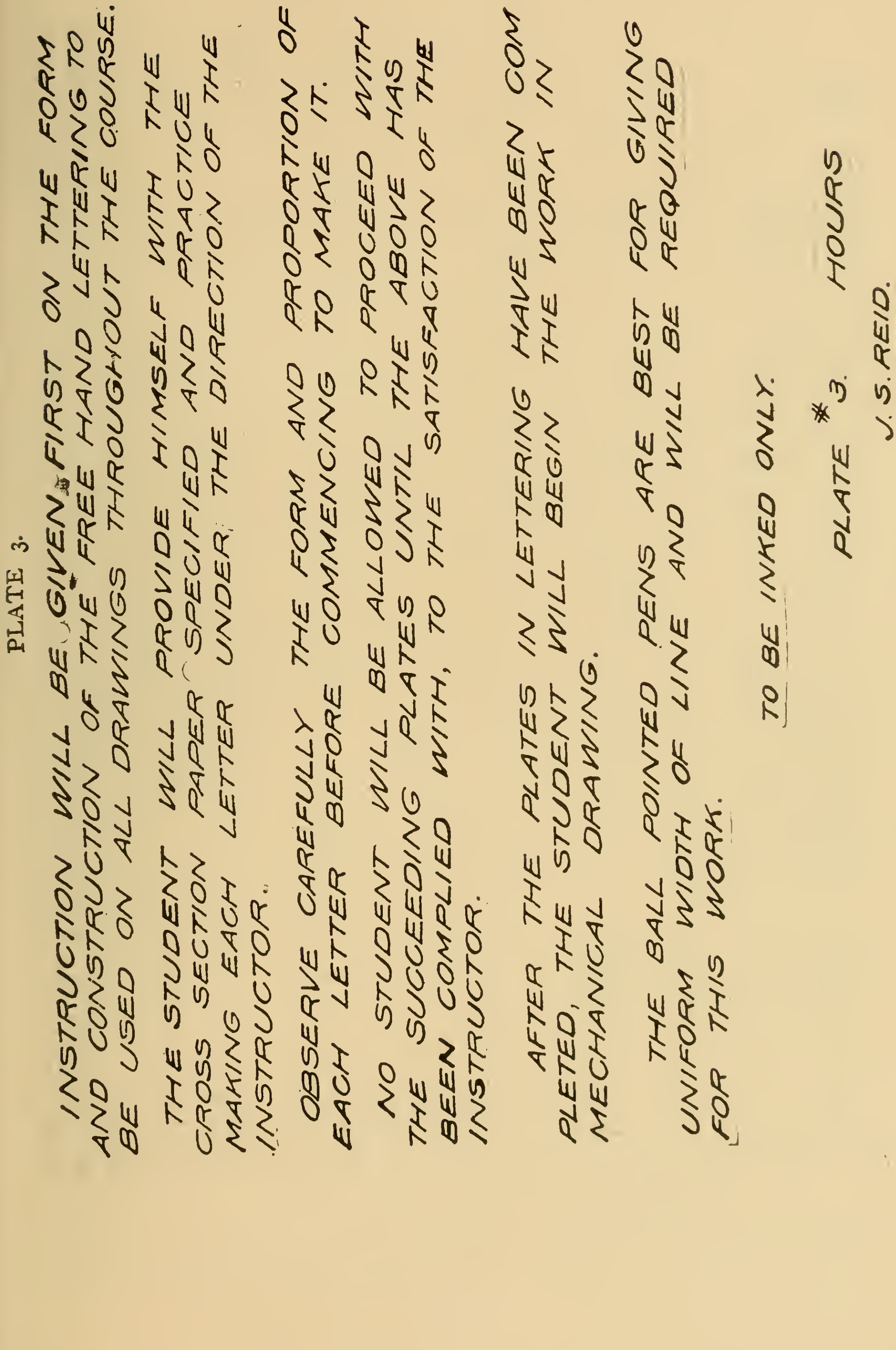


PLATE 3.
INSTRUCTION WILL BE GIVEN FIRST ON THE FORM
AND CONSTRUCTION OF THE FREE HAND LETTERING TO
BE USED ON ALL DRAWINGS THROUGHOUT THE COURSE.
THE STUDENT WILL PROVIDE HIMSELF WITH THE
CROSS SECTION PAPER SPECIFIED AND PRACTICE
MAKING EACH LETTER UNDER THE DIRECTION OF THE
INSTRUCTOR.
OBSERVE CAREFULLY THE FORM AND PROPORTION OF
EACH LETTER BEFORE COMMENCING TO MAKE IT.
NO STUDENT WILL BE ALLOWED TO PROCEED WITH
THE SUCCEEDING PLATES UNTIL THE ABOVE HAS
BEEN COMPLIED WITH, TO THE SATISFACTION OF THE
INSTRUCTOR.
AFTER THE PLATES IN LETTERING HAVE BEEN COM
PLETED, THE STUDENT WILL BEGIN THE WORK IN
MECHANICAL DRAWING.
THE BALL POINTED PENS ARE BEST FOR GIVING
UNIFORM WIDTH OF LINE AND WILL BE REQUIRED
FOR THIS WORK.
TO BE INKED ONLY.
PLATE #3. HOURS
J. S. REID.

FIG. 189.

PLATE 4.

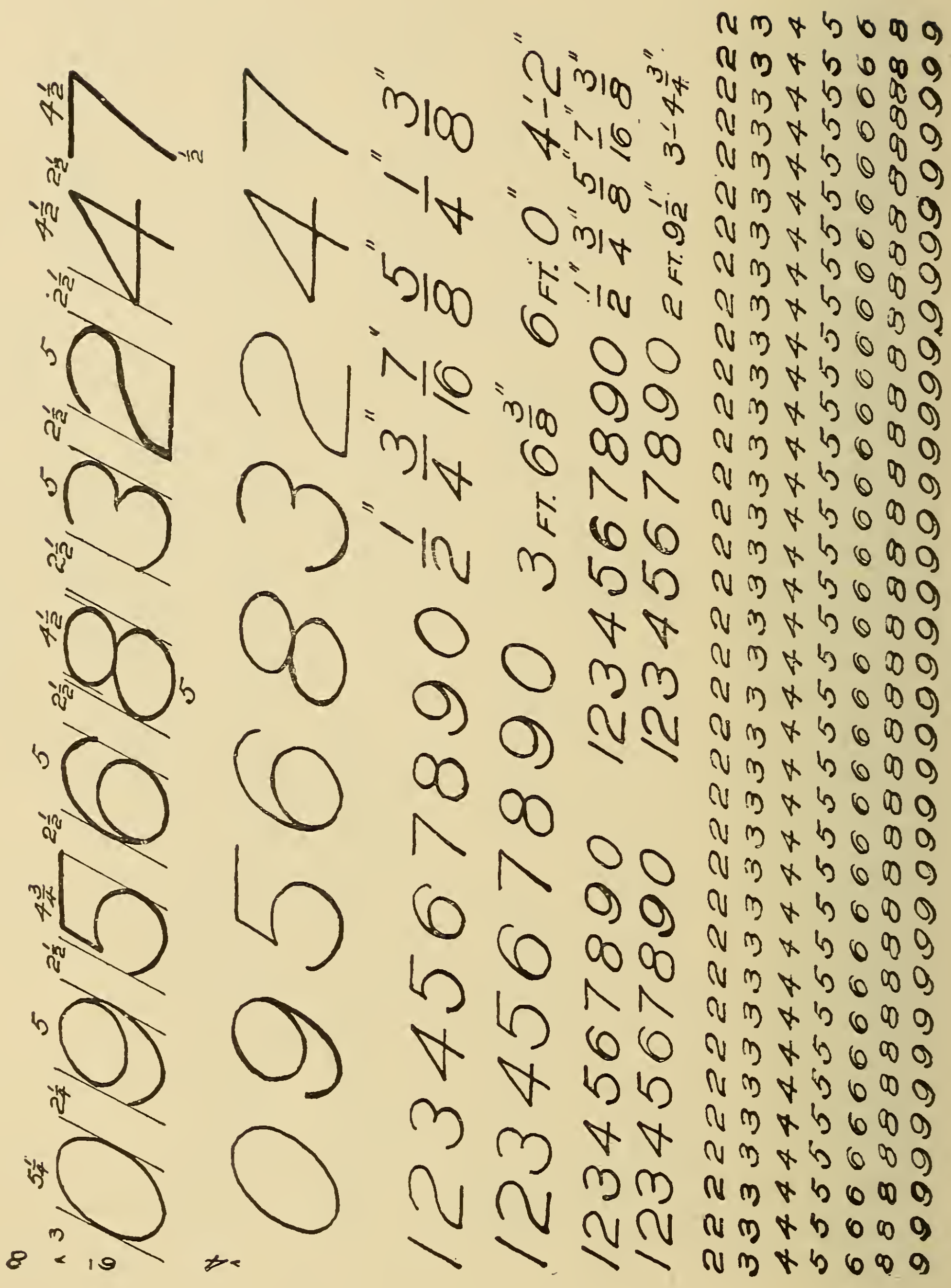


Fig. 190.

Pencil three words only of the small letters at first and submit for criticism before going on with the others.

Use *Ball* pen, No. 506, to ink large letters and No. 516 for small letters and figures.

PLATES 3–6.—In the next three *letter plates* the directions for *guide-lines*, *form*, *slope*, *spacing* of letters, and for *width* of small letters should be carefully observed.

PLATE 6.* While a substantial majority of the leading drafting rooms in the United States are in favor of using Gothic Capitals exclusively for notes and titles, there are a number using a combination of Gothic Capitals and Lower Case letters. So it is deemed wise to introduce one plate of Lower Case letters to give the student some knowledge of their form, proportion and construction.

This plate should first be pencilled and after approval, inked. In addition to the "Ball" pen, No. 516, for large letters, the small letters should be inked with Gillott's No. 303. All pens when new should be "exercised" a little before beginning to letter. The form and proportion of these letters as given by the largest letters in Fig. 192, on page 147, should be adhered to as closely as possible.

In general these letters should be made with down strokes of a uniform pressure. The only exceptions are the letters *r*

---

* All letters and figures should have uniform slope. Letters and figures of one square high should have a full half square slope.

Each *plate* must be signed by Instructor in charge, in pencil before inking and in ink when plate is finished. Plates not so signed will be rejected.

When plates are finished and signed they will be retained by the student until the six plates on *lettering* are completed, when they are to be bound with paper binders and handed to the Instructor.

PLATE 5.

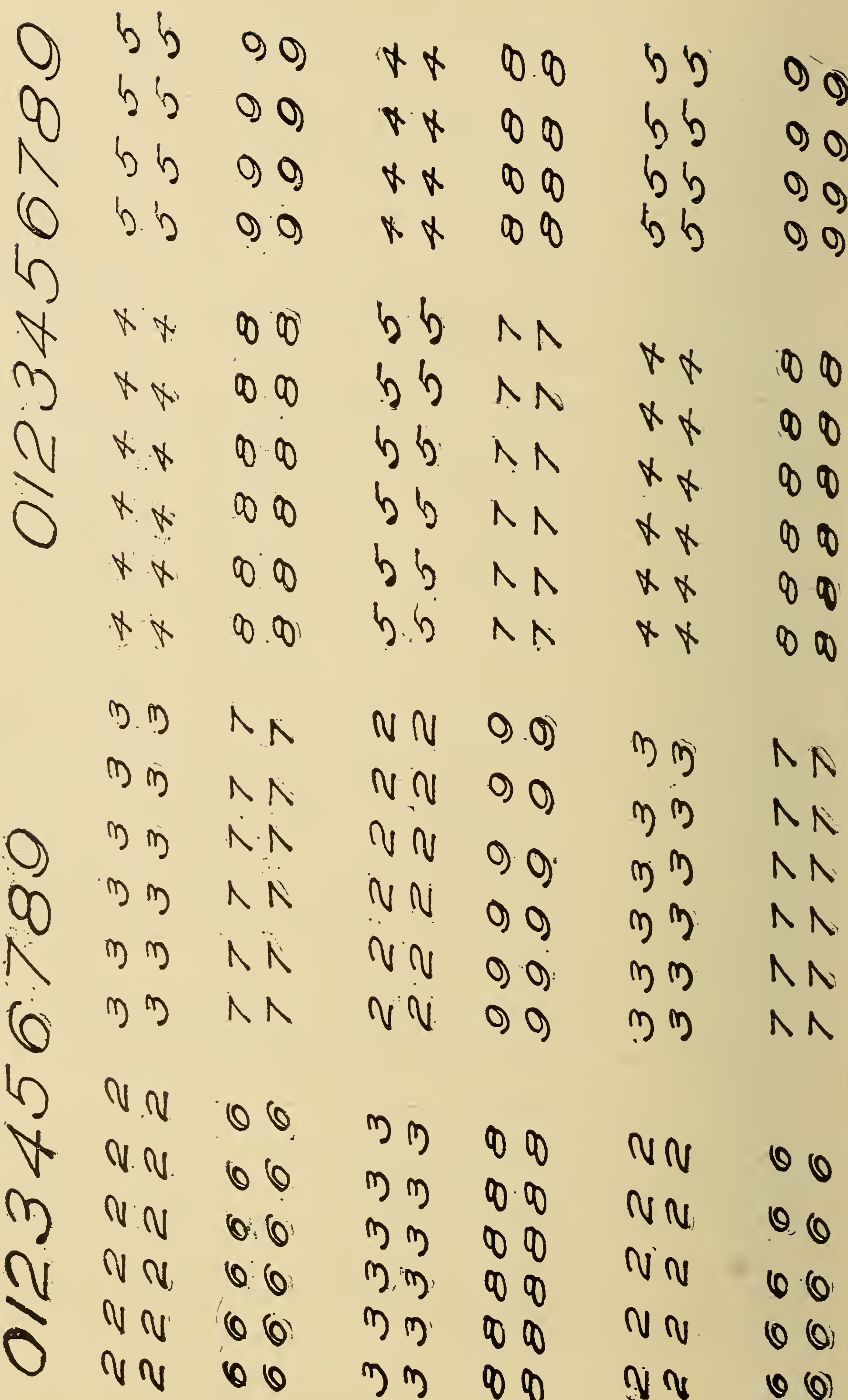


FIG. 191.

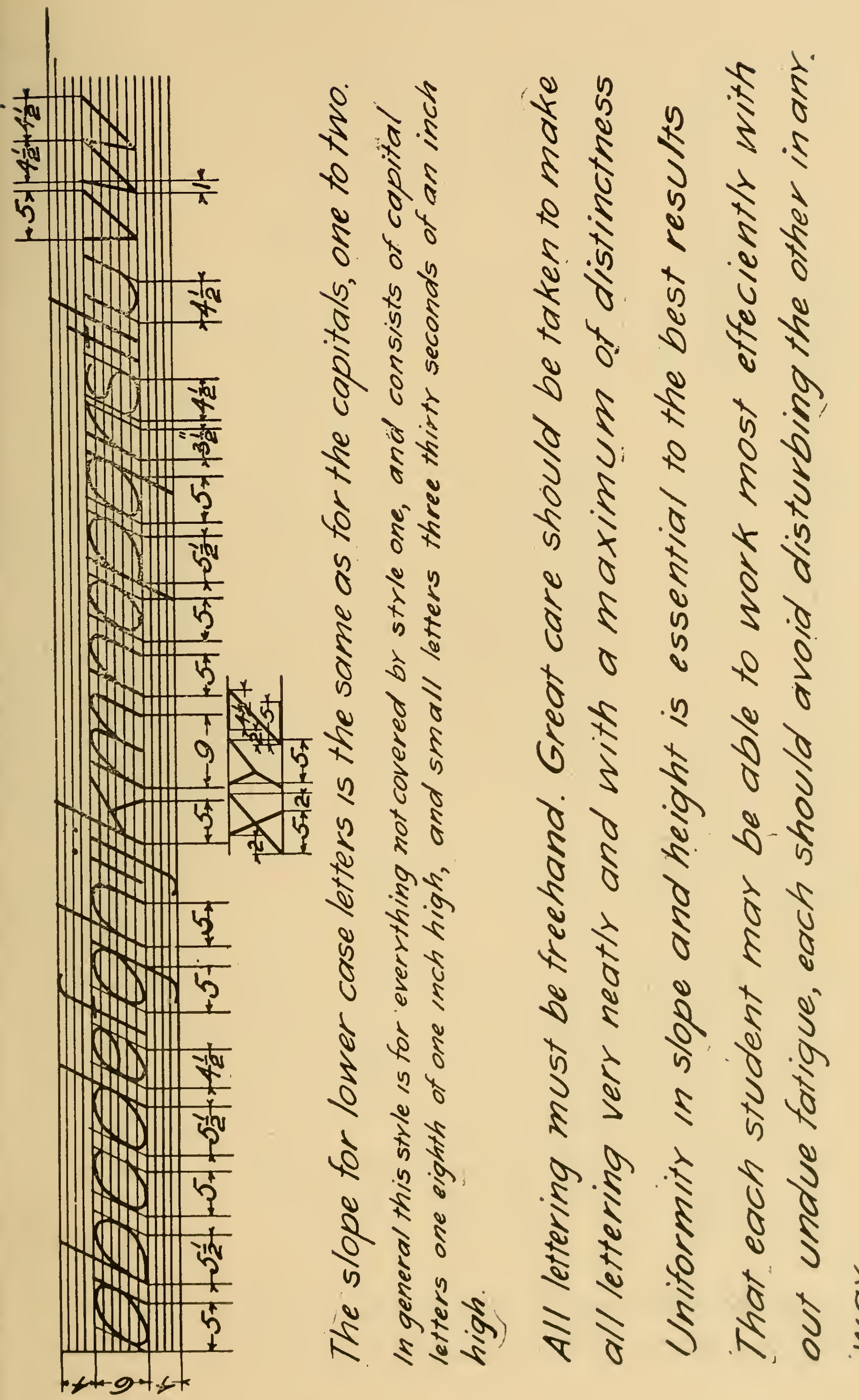

The slope for lower case letters is the same as for the capitals, one to two.
In general this style is for everything not covered by style one, and consists of capital
letters one eighth of one inch high, and small letters three thirty seconds of an inch
high.
All lettering must be freehand. Great care should be taken to make
all lettering very neatly and with a maximum of distinctness
Uniformity in slope and height is essential to the best results
That each student may be able to work most effeciently with
out undue fatigue, each should avoid disturbing the other in any
way.

FIG. 192.

and *u*. The curved part of the *r* may be made with an up stroke curved only at the top. The *u* is made with two down strokes

PLATE 6A.

THERE IS NOTHING ON THE WHOLE DRAWING SO IMPORTANT AS THE DIMENSIONS.

OBSERVE CAREFULLY HOW THEY ARE MADE ON THE BLUE PRINT.

IN PLACING DIMENSIONS ON A DRAWING OBSERVE THESE GENERAL RULES:-

1. DIMENSIONS SHOULD NOT BE PLACED SO CLOSE TO OTHER LINES AS TO IMPAIR CLEARNESS.
2. NEVER PLACE DIMENSIONS ON CENTER LINES.
3. DIMENSIONS SHOULD BE BASED FROM CENTER LINES OR FINISHED SURFACES.
4. ALL DIMENSIONS SHOULD READ FROM THE BOTTOM AND RIGHT HAND SIDE OF A DRAWING.
5. DIMENSIONS ON A DRAWING SHOULD INDICATE THE FULL DIMENSIONS OF THE OBJECT, INDEPENDENT OF THE SCALE OF THE DRAWING.
6. WHEN OVERALL DIMENSIONS ARE REQUIRED THEY SHOULD ALWAYS BE PLACED OUTSIDE OF SUB-DIMENSIONS.
7. SECTION LINING SHOULD GENERALLY BE MADE AT 45 DEGREES.

TO BE INKED ONLY.

Fig. 193.

and the bottom curve filled in with a stroke to the right and upward. The *m*, *n*, and *h* should be formed with nearly sharp upper curves.

This plate will have to be repeated until the desired results have been obtained.

PLATE *6A*, Fig. 193. This is an extra lettering plate for those students who may finish the required plates ahead of time. The extra plate will increase the grade mark.

GEOMETRICAL DRAWING, INCLUDING CONIC SECTIONS; ORTHOGRAPHIC PROJECTIONS; DEVELOPMENTS; INTERSECTIONS; ISOMETRICAL DRAWING, AND ONE WORKING DRAWING.

Before beginning the work in Mechanical Drawing read carefully the directions given on pages 1 to 17. The size of the sheet of cream drawing paper will be 15″×20″. This size will be used for all drawings in mechanical and machine drawing. The border lines and inside divisions will be as shown on page 150, except where otherwise directed.

Use a 6 H pencil sharpened to a long wedge-shaped point, as explained on pages 7 and 8.

The lead in the compasses must also be 6 H and sharpened in the same way. A properly sharpened pencil is necessary to obtain good work.

When the work has been completely pencilled with fine sharp lines it should be submitted to the Instructor for approval and signature, after which the given and required lines of the problem are to be repencilled with a strong, bold line, using a 4 H pencil sharpened to a conical point (not too sharp).

TITLE. The form of title shown in Fig. 194 will be used on all drawings and should be pencilled and inked together with the border lines whether the drawing is to be inked or not. All

drawings are to be *finished pencil* drawings, as directed above, except where otherwise stated.

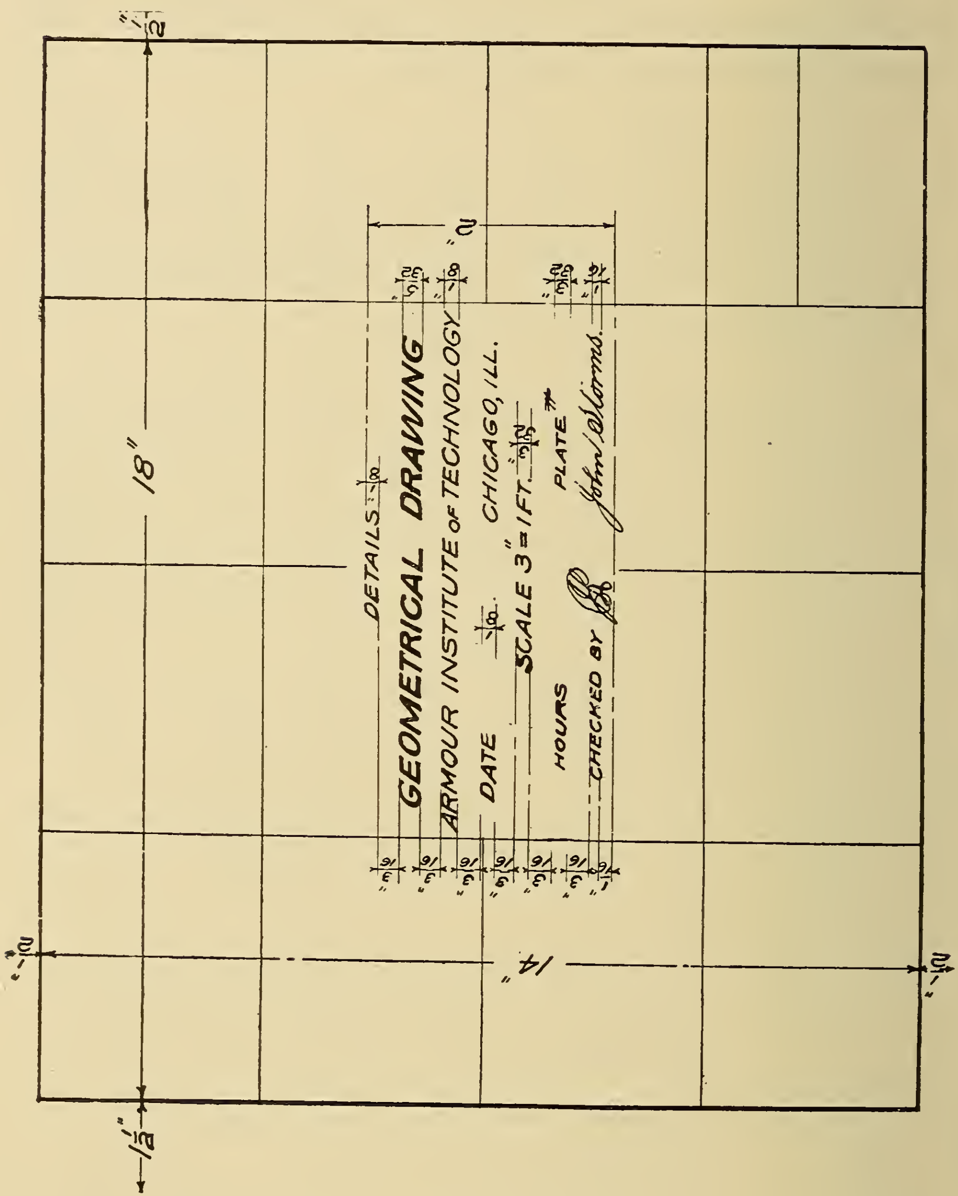


Fig. 194.

Following is a list of the problems to be drawn on each plate:

PLATE 7. (Pages 17 to 26 inclusive.)

Problems 1, 2, 3, 5, 6, 7, 9, 11, 13, 14, 15, 16, 18, 19, and 20. Make the dimensions for each problem to suit the given space so as to comfortably fill it without crowding.

PLATE 8. (Pages 26 to 35.)

Problems 21, 22, 24, 25, 26, 29, 30, 34, 35, 37, 39, 40, 41, 42, and 44.

PLATE 9. (Pages 43 to 53.)

Problems 54, 56, 57, 58, 59. Use four spaces for problem 59: 70, 71 in one space, 72 and 73 in one space, and 63 in two spaces.

PLATE 10. (Pages 39 to 43.)

Conic Sections. Divide the plate into nine equal spaces. Draw problems 47 and 48 (in problem 48 draw complete upper half of ellipse and draw lower half by "Honey's method," problem 46), 49, 50, 51, 52, 53, and 55. Make twice the size given in the figures.

PLATE 11. (Study pages 74 to 89.)

Orthographic Projection. Divide sheet into nine equal spaces, as shown in Fig. 195, page 152.

Problem 1 shows three views of a wedge-shaped solid, viz., the vertical, horizontal, and profile projections. The vertical projection is commonly termed the "Elevation" or "Front Elevation;" the horizontal projection is generally called the "plan," and the profile projection is known as the "End Elevation" or "End View."

It will be seen that the end view is obtained by revolving points projected from the plan to the profile plane through an

PLATE II.

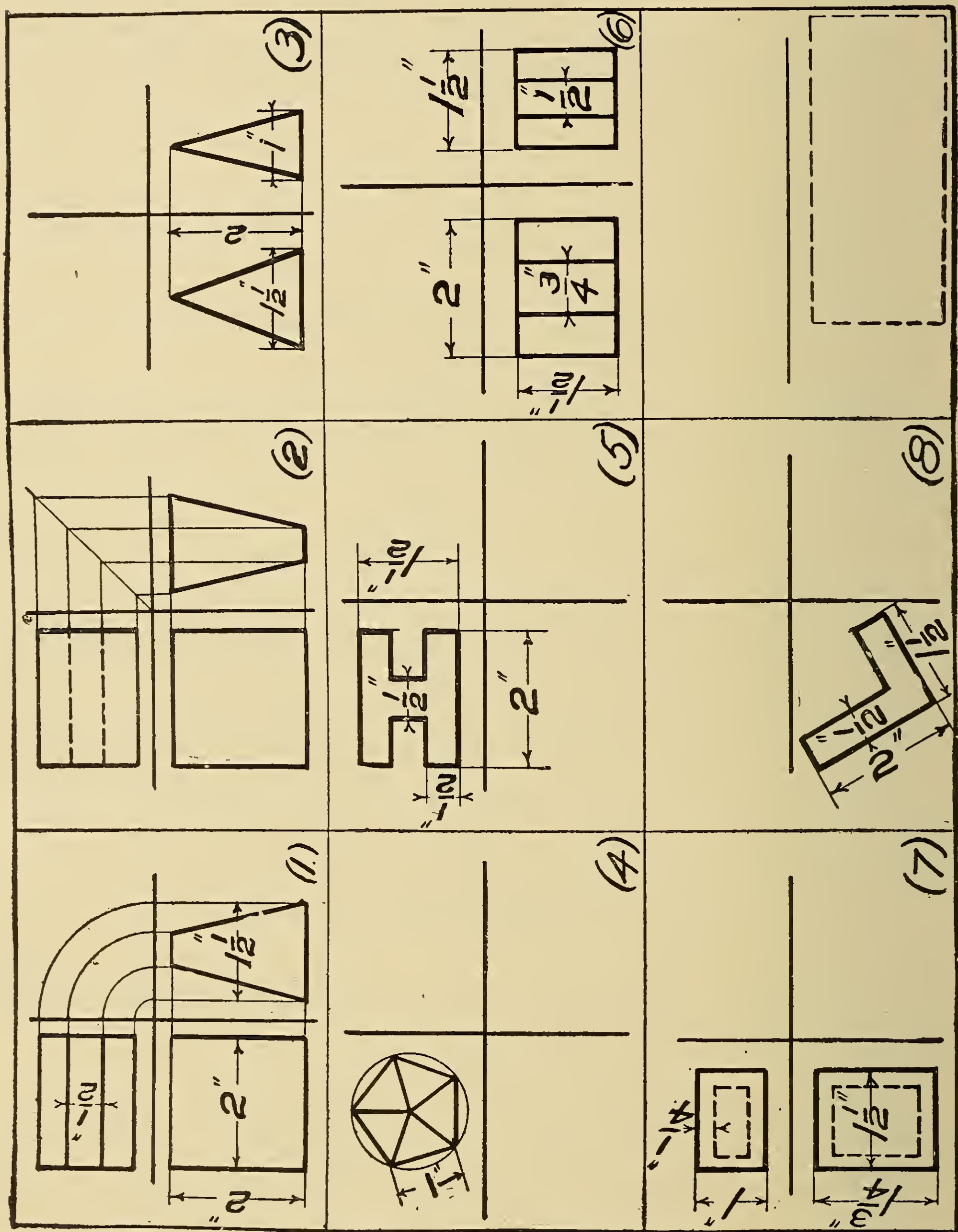


Fig. 195.

angle of 90° by means of arcs of circles and dropping perpendiculars to intersect horizontals from the same points in the elevation.

Problem 2. This is the same solid placed differently and having the end view projected by straight lines instead of by arcs of circles. This method will be adhered to in preference to the other, as it takes less time.

Problem 3. Given the front and end sections of a rectangular pyramid $1\frac{1}{2}''$ wide $\times$ $1''$ thick $\times$ $2''$ high. From the given views draw the plan.

Problem 4. Given the plan of a pentagonal pyramid whose side is $1''$, project the front and end elevations.

Problem 5. Given the plan of an H-shaped block $2''$ high, draw front and end elevations.

Problem 6. Given the elevations of a +-shaped block, draw the plan.

Problem 7. Given front elevation and plan of a hollow rectangular prism, draw the end elevation.

Problem 8. Given the front elevation of an L-shaped block $2''$ long, draw the end elevation and plan. In the title of this sheet leave out the word "Details" and make title *name* "Orthographic Projection."

Plate 12.

Problem 1. Given the elevation and plan of a $1\frac{1}{2}''$ square pyramid $1\frac{3}{4}''$ high, draw the end view.

Problem 2. Given the same pyramid of problem 1 when the plan has been rotated to the left through an angle of $15°$. Project the front and end elevations.

Problem 3. Given the front elevation of the figure obtained in problem 2 when revolved to the left through an angle of $15°$. Draw the plan and end elevation.

Problem 4. Given the front elevation of problem 1 when

revolved through an angle of 30° to the right. Draw the plan and end view.

Problem 5. Given the end elevation of the pyramid obtained in problem 2 when revolved to the right through an angle of 15°. Project the front elevation and plan.

PLATE 12.

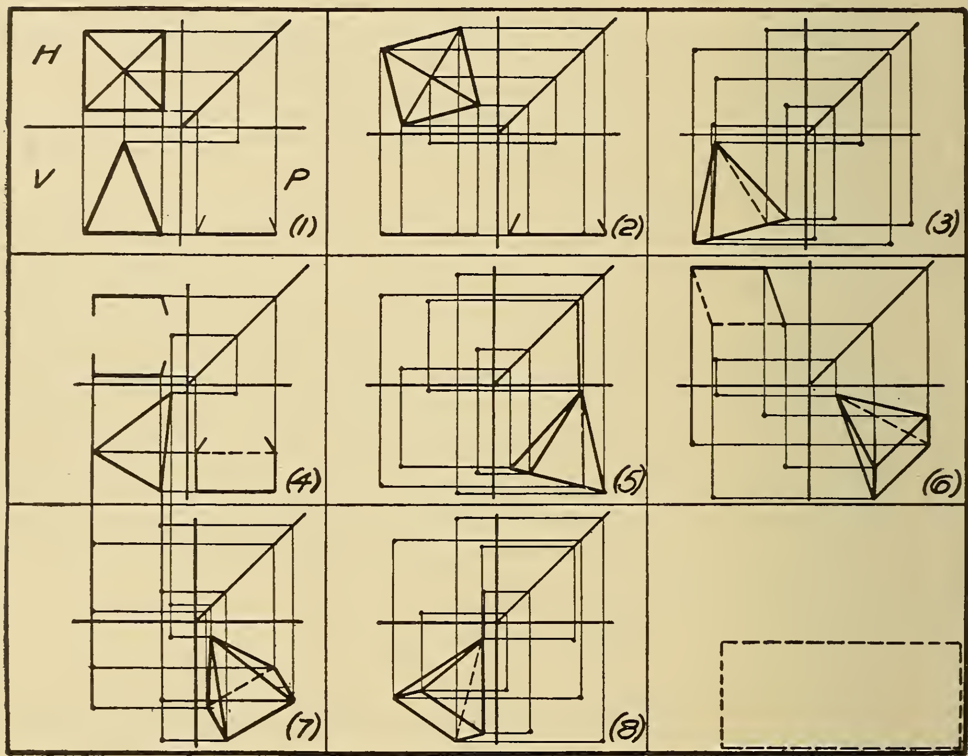


FIG. 196.

Problem 6. Given the end view of the pyramid obtained in problem 3 when revolved to the left through an angle of 45°. Draw the front elevation and plan.

Problem 7. Given the end view of the pyramid obtained in problem 4 when revolved through an angle of 30° to the left. Draw the elevation and plan.

Problem 8. Given the front elevation obtained in problem 5 when revolved 30° to the right. Draw plan and end view. Title similar to that on Plate 10.

PLATE 13.

In the same positions as given above draw the projections of a rectangular prism, Fig. 201, $1\frac{1}{2}'' \times 1'' \times 2''$ high.

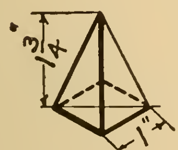


FIG. 197.

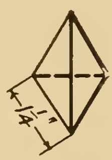


FIG. 198.

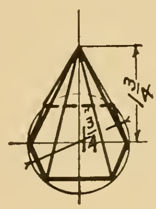


FIG. 199.

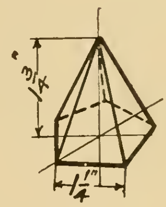


FIG. 200.

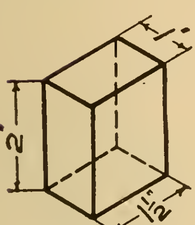


FIG. 201.

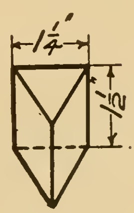


FIG. 202.

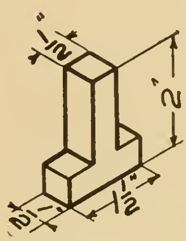


FIG. 203.

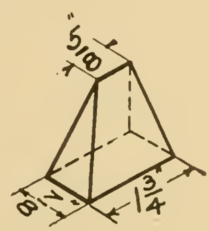


FIG. 204.

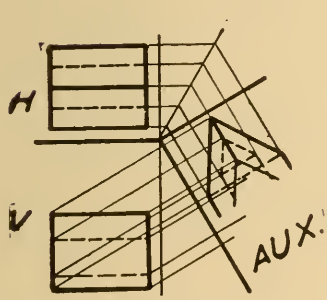


FIG. 205.

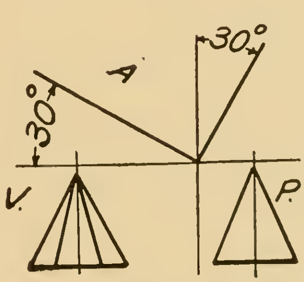


FIG. 206.

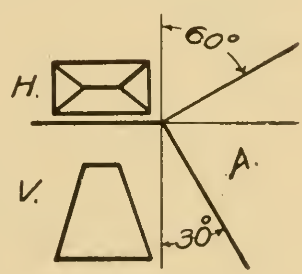


FIG. 207.

PLATE 14.

Using same positions as in Plate 12, draw the projections of a hexagonal pyramid, Fig. 199, circumscribed circle of hexagon $= 1\frac{3}{4}''$ diameter, height $1\frac{3}{4}''$.

PLATE 15.

Given a pentagonal pyramid, Fig. 200, whose side is $1\frac{1}{4}''$, height $1\frac{3}{4}''$, draw the projections of the various positions as required in Plate 12.

PLATE 15 *B*.

In the same positions as given above draw the projections of a triangular prism, Fig. 202, page 155, side of triangle $1\frac{1}{4}''$, height of prism $1\frac{1}{2}''$.

PLATE 15 *C*.

In the same positions as given above draw the projections of a T-shaped block, Fig. 203, page 155.

PLATE 15 *D*.

In the same positions as given above draw the projections of a wedge, Fig. 204, page, 155. Plates 15 *B*, 15 *C*, 15 *D* are extra plates to be drawn by those who finish the required plates ahead of time.

PLATE 16.

Problem 1. Given the elevation and plan of a hollow triangular prism in the position shown in Fig. 205, page 155. Complete the projection in the auxiliary plane.

Problem 2. Given the elevation and end view of a hexagonal pyramid, draw the projection on the auxiliary plane, shown in Fig. 206, page 155. Use same dimensions given in Fig. 199.

Problem 3. Given the elevation and plan of a wedge, draw the projection on the auxiliary plane, shown in Fig. 207, page 155. Use same dimensions given in Fig. 204.

Problem 4. Given elevation, plan, and revolved position of plan of a right circular cone, Fig. 214, page 157. Base 3″ diameter, height 3″. Draw elevation and end view in revolved position. See page 88. In planning position of drawings on

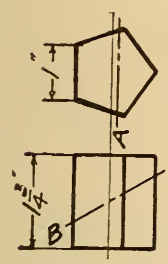


FIG. 208.

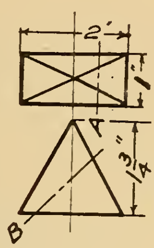


FIG. 209.

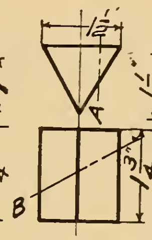


FIG. 210.

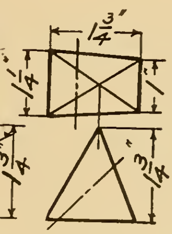


FIG. 211.

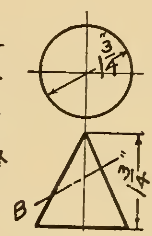


FIG. 212.

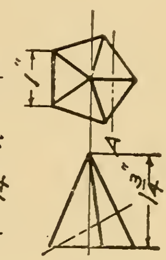


FIG 213.

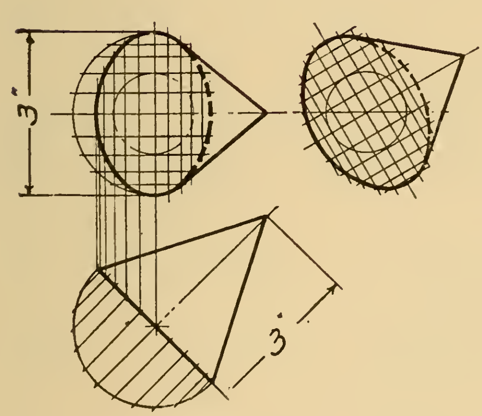


FIG. 214.

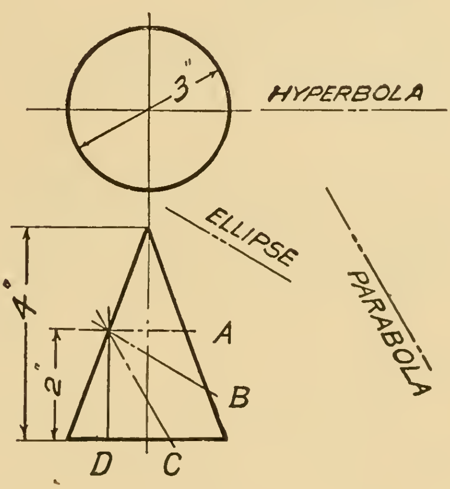


FIG. 215.

this plate, locate problems 1, 2, and 3 along the top of the sheet and problem 4 in the lower left hand.

PLATE 17. DEVELOPMENTS.

Scheme the layout of all the problems in this plate before beginning to draw.

Problem 1. Given the elevation and plan of a pentagonal prism, Fig. 208, page 157, 1″ side, $1\frac{3}{4}$″ high, cutting planes *A* and *B*, draw projections as shown in Fig. 125, page 90. Draw the development of the part below the cutting plane *B*. See Fig. 126, page 90.

Problem 2. Given elevation and plan of a rectangular pyramid, Fig. 209, page 157, 2″×1″×$1\frac{3}{4}$″ high, and cutting planes *A* and *B*. Draw projections and development as required for problem 1.

Problem 3. Given views and cutting planes of equilateral triangular prism shown in Fig. 210, page 157. Draw sections and development.

Problem 4. Given views and cutting planes of pyramid shown in Fig. 211, page 157. Draw sections and development.

In this problem when laying out the development, allowance must be made for the unequal inclined edges of the sides of the pyramid. See Fig. 117, page 82.

Plate 18.

Problem 1. Given the right circular cone, as shown in Fig. 212, page 157. Draw sectional plan and development.

Problem 2. Given pentagonal pyramid, Fig. 213, page 157, and cutting planes *A* and *B*. Draw sections and development.

Problem 3. Given projections of right circular cone, Fig. 215, page 157, and cutting planes *A*, *B*, *C*, and *D*. Draw the projections of conic sections as indicated by center lines. Draw also development of part of cone below cutting plane *B*. If space will not permit of full development draw half. See Fig. 130, page 95.

Plate 19. Intersections.

Problem 1. Draw three views of two right circular cylinders of equal diameter, shown in Fig. 216, page 159, intersecting at right angles to each other. Draw curve of intersection. See page 96.

FIG. 216.

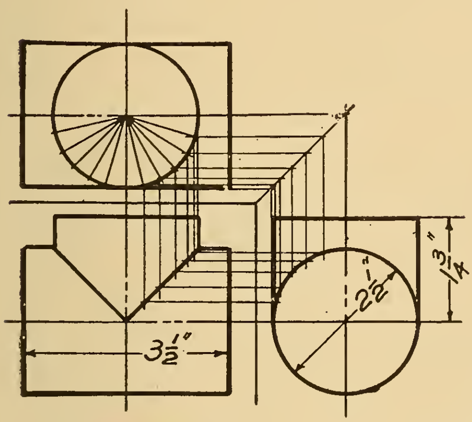
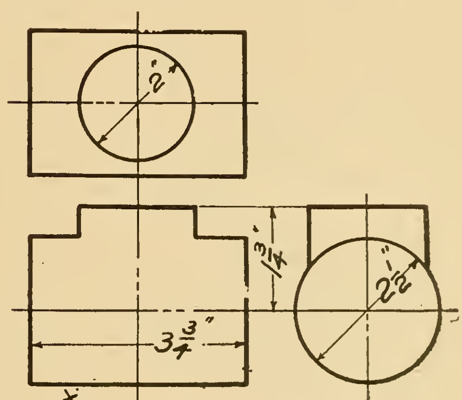


FIG. 217.



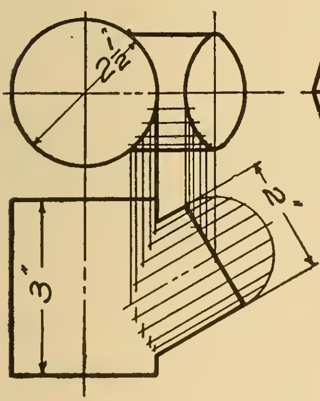


FIG. 218.

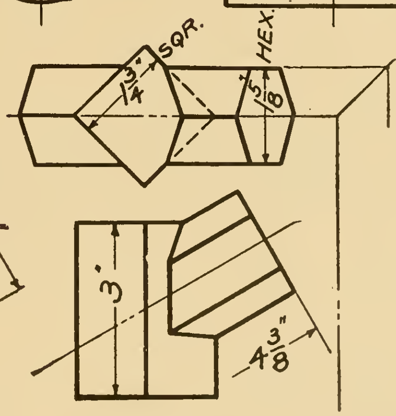


FIG. 219.

Problem 2. Make the drawing shown in Fig. 217, page 159, and draw curve of intersection.

Problem 3. Make drawing shown in Fig. 218, page 159, and project curve of intersection.

Problem 4. Fig. 219, page 159, shows a square prism intersected by a hexagonal prism partly shown in elevation. Com-

plete the elevation and draw also half end view. Total length of hexagonal prism $4\frac{3}{8}''$.

Plate 20.

Problems 1 and 2. Construct the curves of intersection shown on the connecting-rod ends in Figs. 140 and 141, page 102, and draw three complete views of each.

Problems 3 and 4. Draw the projections of a "V" and "Square" threaded screw according to directions given on pages 99 and 100, Figs. 137 and 138.

Plate 21. Isometrical Drawing.

See pages 122 and 123.

Problem 1. Make the isometrical drawing of a $2\frac{1}{4}''$ cube. Draw a $2\frac{1}{4}''$ isometric circle on the upper face by the method shown in Fig. 171, page 127. From the lower left-hand corner of the right-hand face lay off angles of 15°, 30°, and 45°. Use method shown in Fig. 174, page 127. See problem 41, page 129.

Problem 2. Draw the hollow cube as shown in Fig. 170, page 126, except that instead of the hollow block on the upper face draw a cylindrical prism of $1\frac{3}{4}''$ diameter and 1″ high.

Problem 3. Make the isometrical drawing of a hexagonal headed bolt, shank 1″ diameter and 2″ long. Head 1″ thick. Use either of the methods shown in Figs. 173 and 175, page 127.

Problem 4. Make the isometrical drawing of a pentagonal prism of $1\frac{7}{8}''$ sides and $2\frac{1}{2}''$ high. On the top of the prism draw an isometric circle of 2″ diameter. See Fig. 176, page 127.

Problem 5. Make the isometrical drawing of the tool box shown at Fig. 183, page 128. Dimensions $3\frac{1}{2}''$ long $\times$ 2″ wide $\times$ 1″ deep, over all. Cover and sides $\frac{1}{4}''$ thick. Use the method of

offsets shown in Fig. 182, page 128. Place full dimensions on this drawing. Plate 21 is to be finished in pencil and inked. See directions for inking with the spring bows on page 14, the

PLATE 22.

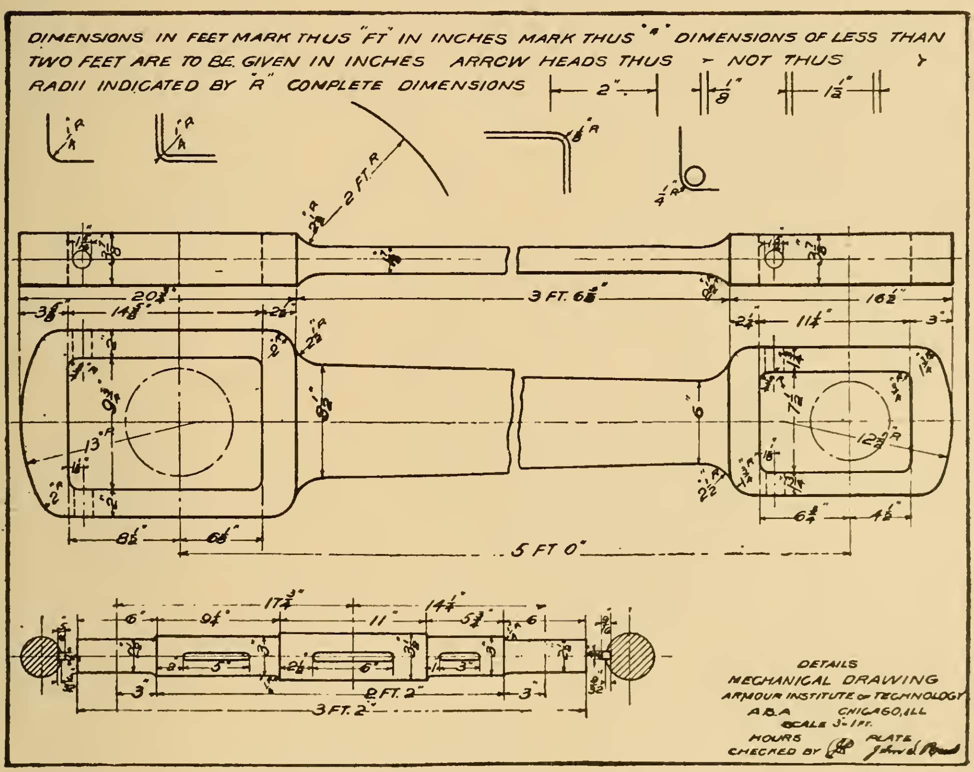


FIG. 220.

large compass on page 13, and the ruling pen on page 9. See also directions given for inking Plate 22 on page 161.

PLATE 22. WORKING DRAWING.

Problems 1 and 2. Make the working drawing of connecting rod and axle shown in Fig. 220, page 161. Begin by laying off the border line and space for title. Draw guide-lines $\frac{1}{8}''$ high and $\frac{1}{4}''$ space between lines. Locate all center lines of rod and

axle. Use 6 H pencil sharpened as directed on page 8. Draw fine, clear, clean-cut lines. When drawings of rod and axle

PLATE 22F.

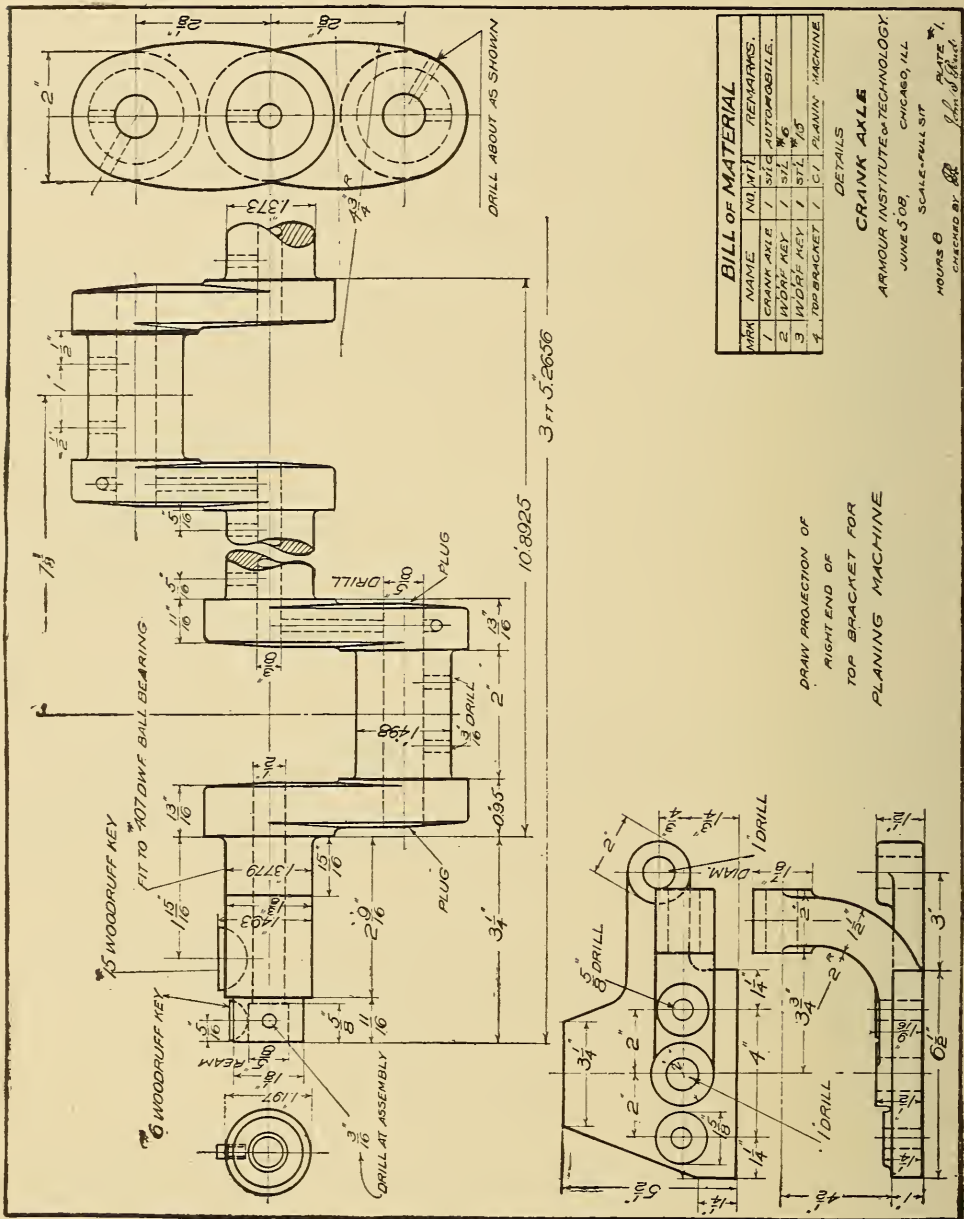


FIG. 221.

are complete and approved, strengthen the lines with 4 H pencil, conical point. Then draw dimension lines. Next put in arrow-

heads and dimensions, beginning at the upper left hand and working down toward the lower right-hand corner.

When the drawing is properly finished in pencil and signed by the Instructor it will be ready for tracing on cloth. Begin the tracing with the spring bow pen. Ink all arcs of circles, circles, and irregular curves before inking any straight lines. Then ink dimension lines. Next ink arrow-heads and dimensions in consecutive order, beginning with the left-hand arrow-head, then dimension, next sign of inches, and then left-hand arrow-head. Ink hatch lines and center lines last of all. For weight and character of lines see "Conventions" on page 165.

Plate 22 *F*.

Problem 1. Make drawing of automobile crank axle, as shown in Fig. 221, page 162. Use same directions for pencilling and inking as given for Plate 22.

Problem 2. Make drawing of top bracket for planing machine, as shown in Fig. 221, page 162. Project also right end view of bracket. Make finish pencil drawing and trace on cloth.

This plate is not required in the course of mechanical drawing, but credit will be given for it in the Freshman Course to those who may have time to finish it in this course. A higher mark will be given to the student completing this plate in addition to the required plates.

Course I is preparatory to Courses II and III in Machine Drawing and Design.

Courses II and III are given in "Mechanical Drawing and Elementary Machine Design," by John S. and D. Reid, John Wiley & Sons, New York.

PRESENT PRACTICE IN DRAFTING ROOM CONVENTIONS AND METHODS IN MAKING PRACTICAL WORKING DRAWINGS.

SUMMARY REPORT OF AN INVESTIGATION MADE BY THE WRITER WITH THE AUTHORITY OF THE ARMOUR INSTITUTE OF TECHNOLOGY, CHICAGO, ILL., INTO THE PRESENT PRACTICE OF THE LEADING DRAFTSMEN IN THE UNITED STATES, IN THE USE OF STANDARD CONVENTIONS AND METHODS WHEN MAKING COMMERCIAL WORKING DRAWINGS.

A circular letter accompanied by a list of thirty-five questions was submitted to two hundred leading firms in the United States, embracing nearly all kinds of engineering practice.

The returns have been exceedingly gratifying, and especially so has been the spirit with which the "Questions" have been received and answered.

Many requests have been received from chief draftsmen for a copy of the returns.

The questions submitted and the answers received are given somewhat in detail below.

Q. 1. Do you place complete information for the shop on the *pencil drawing*, such as all dimensions, notes, title, bill of material, scale, etc.?

Complete information is placed on drawing before tracing.	57
Complete information is placed on tracing only	42
Principal dimensions and title only on pencil drawing	2
Draw directly on bond paper	10
Did not answer this question...........................	10
Sometimes	7

Reasons given for making the pencil drawing complete:

To arrange notes. To save ime. The tracing is not usually made by the draftsman who makes the pencil drawing.

Q. 2. Do you ever ink the pencil drawing?

Never ink the pencil drawing	91
Generally ink the pencil drawing	7
Sometimes ink the pencil drawing	8
Sometimes ink the pencil drawing and shellac it for shop use.	1
Use bond paper	10
Make pencil drawings on dull side of tracing cloth........	2
Ink center lines of assembly drawing	1
Ink center lines of pencil drawings in red	2

Q. 3. Do you trace on cloth and blue print?

Always trace on cloth and blue print	102
Blue print from bond paper	10
Blue print from bond paper occasionally	1
Sometimes make "Vandyke" prints for shop use	1
Sometimes use paper drawings in shop for jigs and fixtures.	1

Q. 4. Do you use blue prints entirely in the shop?

Use blue prints altogether in shop	105
Sometimes use pencil drawings or sketch	21

Sometimes use sketches made with copying ink	1
Sometimes use prints from "Vandyke"	1
Use white prints mounted on cardboard and varnished	1
Use blue prints mounted on cardboard	1
Use sketches for rush work	1

Q. 5. When tracing do you use uniform wide object lines? Ever use shade lines?

Use uniform, thick object lines. Never use shade lines	100
Sometimes use shade lines	21
Use shade lines on small details	5
Always use shade lines	14
Experts in the use of shade lines may do so to make drawings clear	1
Shade rounded parts	1

Q. 6. What kind of a center line do you use?

Long dash, very narrow, and dot, thus:	42
Long dash and two dots,	29
Very fine continuous line,	19
Very fine dash line, long dashes,	8
Long dash and dot in red,	3
Continuous fine red line,	8
Long dash and three dots,	1
Long dash and two dots, thus:	1

Q. 7. What kind of dimension line do you use?

Continuous fine line, broken only for dimension	52
Fine long dash line,	32
Fine long dash line and dot,	13
Fine continuous red line,	8
Fine continuous blue line,	4
Fine continuous green line,	1

Same character of line as center line, ...	2
Dotted line, -	1
Long dash and two dots,——————— - - ———————	2
Heavy broken lines, —————— —————— ——————	1

Q. 8. What style of lettering do you use? Sloping? Vertical? Free-hand? All capitals of uniform height? or capitals and lower case?

Free-hand sloping	52
Free-hand vertical	45
Free-hand capitals, Gothic, uniform height	61
Free-hand capitals, and lower case	40
All caps, initials slightly higher	5
Lettering left to option of draftsman	2
Mechanical lettering, all caps.........................	3
Not particular, the neatest the draftsman can make free-hand	4
Mechanical lettering, all caps, sloping	2
Give great latitude in lettering, only insist it be bold and neat	1
Roman, caps and lower case, free hand	2
Large letters $\frac{3}{16}$ths, small $\frac{3}{32}$ds and $\frac{1}{8}$th	2

Q. 9. Are your titles and bills of material printed or lettered by hand?

Lettered by hand....................................	79
Standard titles printed and filled in by hand	12
Bill of material table printed and lettered by hand.........	12
Lettered by hand, contemplate having them printed.......	1
B. of M. typewritten on separate sheet and blue printed...	8
Titles partly printed and filled in by hand	8
Use rubber stamp for standard title, fill in by hand........	6
Standard title, bill of material lithographed on tracing cloth..	8

Q. 10. Do you use a border line on drawings?

Always use border lines	97
Never use border lines	13
Use border lines on foundation plans, to send out	1
No border lines on detail drawings	1
Intend to discontinue the use of border lines	1
Border lines used only on design drawings	1
Only on drawings to be mounted on cardboard	1
Only used for trimming blue print	2
On assembly drawings only	1

Width of margins reported: 1″, $\frac{1}{2}$″, $\frac{3}{8}$″, $\frac{1}{4}$″, and $\frac{1}{8}$″.

Q. 11. When hatch-lining sections, do you use uniform or symbolic hatch lines?

Standard symbolic lines	59
Uniform hatch lines for all materials	44
Shade section part with 4H pencil and note name of material	4
Symbolic hatch lines and add name of material	3
Uniform hatch lines for metal only	1
Uniform on details, symbolic on assembly drawings	5
Pencil hatch on tracings and note material other than cast iron	1
Uniform hatch lines, sometimes solid shading	1
No uniform system	1
Sections tinted with water colors representing the metals	1

Q. 12. Is the pencil drawing preserved? Is the tracing stored or do you make "Vandyke" prints for storing away?

Store tracings only	96
Pencil drawings preserved for a time	30
Pencil drawings preserved	13
White prints made and bound for reference	1
Tracings kept in office for reference, blue prints stored	9
"Vandyke" prints stored	1

Use "Vandyke" as substitute for tracing	2
Arrangement drawings preserved, detail drawings destroyed after job is completed. Pencil drawings used for gasket paper	1
Original pencil drawing inked and stored	1
Assembly drawings and layouts preserved	4
Patent office drawings preserved	1
Tried "Vandyke" but found it unserviceable, tearing easily.	1

Q. 13. Do you use 6H grade of pencil for pencil drawings or what?

6H	73
4H, mostly for figures and letters	52
5H	16
Ranging from 2H to 8H	53

Q. 14. Do you use plain orthographic projection for free-hand sketches? Ever use perspective or isometrical drawing for sketches?

Plane orthographic 3d angle projection	99
Isometrical drawing for sketches	25
Perspective for sketches	1
Isometric for piping layouts and similar work	8
Perspective and isometric for catalogue work	2
Isometric sometimes	6
Never use free-hand sketches	6

One says, "When we run into other than orthographic, men are too timid and not sure of themselves. In perspective drawings when work is cylindrical, workmen get mixed up on center lines.

Q. 15. What sizes of sheets do you use for drawings?

9″×12″	13
12″×18″	16

18″×24″	20
24″×36″	19

There seems to be little uniformity in the sizes of shop drawings, about 67 firms reporting different combinations. A few have no system but simply make the size of sheet to suit the object to be drawn.

Q. 16. Do you use red ink on tracings?

Never use red ink on tracings	57
Recently discarded the use of red ink	2
Use red ink for pattern figures	1
Use red ink for center and dimension lines	8
Use red ink for check marks	1
Use red ink for existing work on studies	1
Use red ink sometimes	2
Use red ink on occasions when it is desired to show old work in red and new work in black (use carmine)	1
Use carmine for brick	1

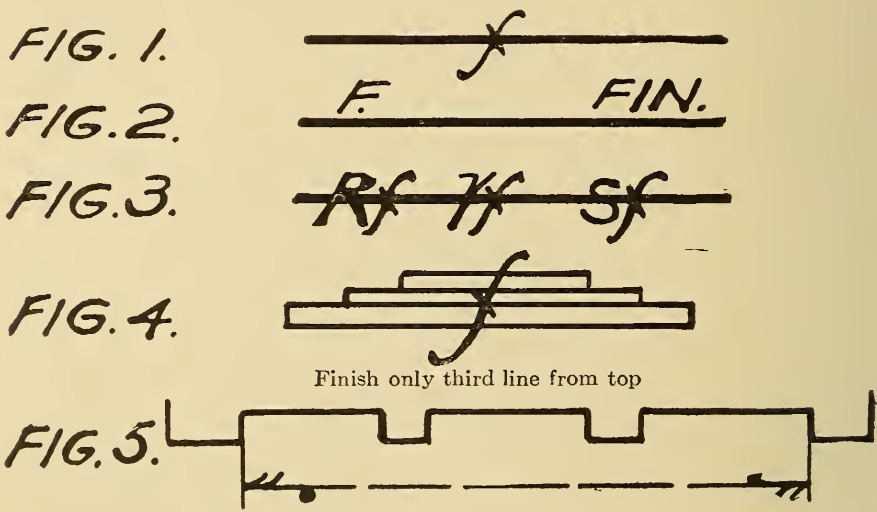
Qs. 17 and 27. How indicate finished surfaces on drawings? When finished all over? When "file finished," ground, planed, bored, drilled, etc.?

Finished surfaces indicated as in Fig. 1	65
Finished surfaces indicated as in Fig. 2	16
Finished surfaces indicated as in Fig. 3	8
Finished surfaces indicated as in Fig. 4	2
Finished surfaces indicated as in Fig. 5	2
Bound the surfaces with red lines	2
Bound the surfaces with dotted lines	2
Name the finish by note in full	68
Do not specify machinery method	6

(See drawing.)

Q. 18. Do you use horizontal or sloping lines for convention in screw threads?

Sloping lines, see Fig. 6 94
Horizontal lines, see Fig. 7 12



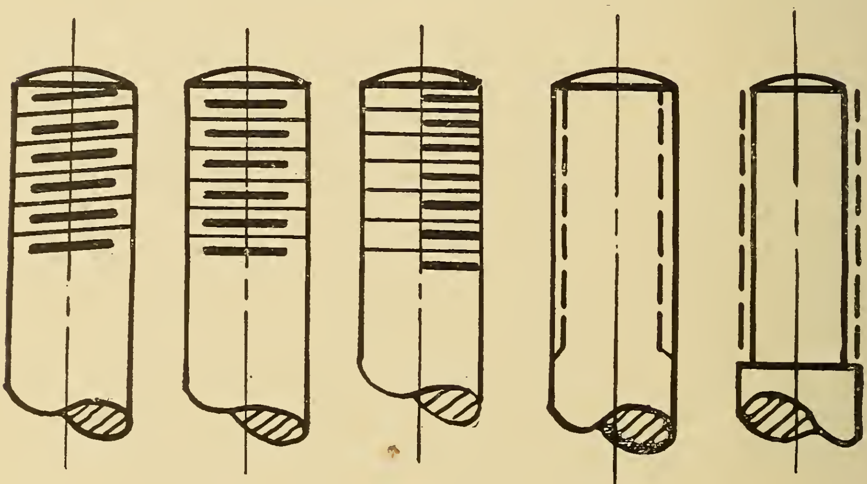


FIG. 6. FIG. 7. FIG. 8. FIG. 9. FIG. 10.

Horizontal lines, see Fig. 8 13
Both 7
Neither, but as shown in Fig. 9 1
Neither, but as shown in Fig. 10 1

Q. 19. When a large surface is in section do you hatch-line around the edges only?

Hatch-line edges only	62
Sometimes	3
Hatch section all over	54
Do not use hatch lines; shade the whole surface with 4H pencil	3
Usually show a broken surface line	1

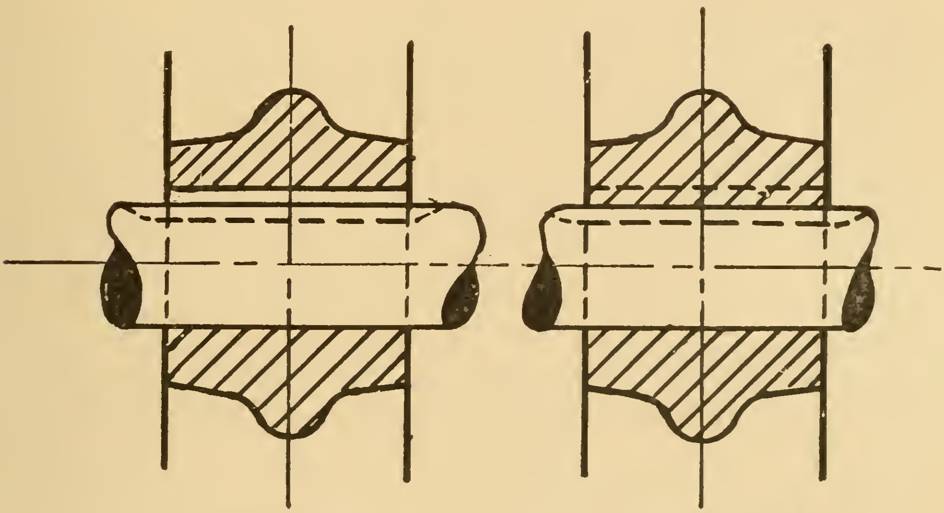


FIG. 11. FIG. 12.

Q. 20. Do you section keyways in hubs or show by invisible lines?

Section keyways as shown in Fig. 11	73
Show keyway by invisible lines, see Fig. 12	40
Keyways in hubs left blank	1

Q. 21. In dimensioning do you prefer to place the dimension upon the piece or outside of it?

Outside whenever possible	92
Upon the piece	13

Both, according to size and shape of part	19
No rule	1

Commenting on placing dimensions outside of piece one says, "It entails less confusion to workman." Another says: "So as to make detail stand out."

Q. 22. Do you use feet and inches over 24 inches?

Yes	69
Use feet and inches over 36″	4
Use feet and inches over 24″ on foundations and outlines	2
Use feet and inches over 48″	6
All inches	21
For pulleys use inches up to 48″	1
Inches up to 10 feet	2
Start feet at 24″ thus: $2\overset{\shortmid}{-}0''$	2
Usually, but not always	2
Yes, except pitch diameters of gears, which are all given in inches	2
Yes, except in boiler and sheet iron work	3
Use feet and inches over 12″	6
Inches up to 100″	3
Inches up to 60″	1

Q. 23. How do you indicate feet and inches? Thus 2 ft. 4″, or thus $2\overset{\shortmid}{-}4''$?

$2\overset{\shortmid}{-}4''$—97, 2FT. 4″—5, 2 FT. 4″—2, 2ft. 4″—13. Both 2ft. 4″ and $2\overset{\shortmid}{-}4''$—1, 2FT. 4 IN.—1, 2′ 4″—8, $2\overset{\scriptscriptstyle >}{-}4^{\scriptscriptstyle \gtrless}$—1.

Q. 24. Do you dimension the same part on more than one view?

One view	94
More than one view as check	46

Q. 25. When several parts of a drawing are identical would the dimensioning of one part suffice for all, or would you repeat the dimension on each part?

One part only	82
Would repeat or indicate by note	39
"Left to judgment of draftsman"	1

"When it is evident that several parts are identical the dimensioning of one part would suffice, 'Would never leave room for doubt.'"

Q. 26. Do you write R for radius or RAD.? D. for diameter or DIA.?

RAD . . 35	Rad . . .47	R 32	rad. . . 1	r 3
DIA . . 41	Dia . . 48	D. . . . 15	d 3	dia . . . 4
	DIAM 1	Diam. . . . 3	diam 5	

Do not use R. or RAD., dimension only 1

Q. 28. Do you always give number of threads per inch? When you do how are they indicated?

Only give number of threads when not standard 67

All others always indicate number of threads in a great variety of ways. A few of the different styles of noting the threads are given below:

$\frac{3}{4}''$—10 Thr. 5THDS. PER 1″. 8thds. 4 threads per inch. Mach. Screw 10–24, $1\frac{1}{4}''$ XII, 16 P. RH. Vth. U. S. S. XVIII, 1″–8–U. S. S. 1″ TAP, 8 PITCH, 3 TH'D R. H. SQ. DOUBLE, 5″–18 THDS. R. H. OWN ST'D 10 thds. per inch. For pipe tap thus, $\frac{1}{2}''$ P.T., etc., etc.

Q. 29. How do you "Mark" a piece to indicate on the bill of material?

Number it on drawing and put a circle around it 34

By name or letter	35
By pattern number	2
By symbol and number	14

Castings, I, II, III, Forgings, 1, 2, 3.

Q. 30. When a working drawing is fully dimensioned why should the scale be placed on the drawing?

For convenience of drafting room	25
Check against errors	11
Not necessary	18
Scale not placed on shop drawings	18
For convenience in calculations and planimeter work	1
To give an idea of over-all dimensions when these are not given. "We never saw a drawing so fully dimensioned as to warrant leaving off the scale"	2

"If a drawing is to scale the scale should be on the drawing, whether it is needed or not."

"It gives every one interested a better conception of the proportions of the piece, and there are frequently portions of a design which do not require a dimension for the shop to work to, and which it is interesting to scale from an engineering point of view."

"To get approximate dimensions not given on drawing."

"Impractical to dimension all measurements for all classes of work."

"Scale will tell at a glance, dimensions would have to be scaled."

"To obtain an idea of relative size of parts without scaling the drawings."

"To sketch on clearance." "To proportion changes." "When erecting to measure over-all sizes."

"In case a dimension has been left off, the scale will help out."

"This is a question of opinion; some will not have the scale, others insist on it." "We always give the scale."

"It is an immense help and time saver in the drawing room."

"Generally no reason. In our work we combine standard apparatus by 'fudge' tracing, and it is convenient to know scale so all parts will surely be to same scale."

"In discussing alterations, additions, clearances, etc., it is convenient to know the scale instantly."

"For convenience in drafting room. We often put an arbitrary scale on with a reference letter indicating scale to draftsman."

"To give toolmaker an idea of the size of the finished piece."

"As an aid to the eye in reading."

Above are some of the reasons given for placing the scale on the drawing. Below are given a few of the reasons why some do not place the scale on the drawing.

"Scale should never be used in shop," says one.

"Not necessary. Sometimes drawing is made out of scale."

"Not advisable, on account of workmen getting into the habit of working to scale instead of to the figures."

"Know of no good reason at all."

"Believe it best to leave scale off."

"Should not. Drawing should never be scaled."

"Know of no good reason why it should be."

"Should not be given on drawing."

"Do not object if left off, not needed."

Q. 31. Do you use the glazed or dull side of tracing cloth?

Dull side . . . 66 Glazed side . 32 Both 4

"Dull side, because it lies flat better in drawers."

"Dull side, so that changes which may be necessary while work is under construction, can be made easily in pencil and later in ink."

"Dull side so tracings may be checked in pencil."

"It prevents curling."

"Both, although the glazed side when traced on lies better in the drawer."

"We use cloth glazed on both sides, work on convex side, so that shrinkage of ink will eliminate camber."

"Dull, except for U. S. Government, who requires the glazed side to be used."

Q. 32. How do you place pattern numbers on castings?

Pattern number with symbol or letter is placed on or near the piece, e.g., PATT.–D–478–C	36

This question was not happily stated: most answers gave "raised letters cast on," while the question like all the others refers to the marking of the drawing.

Q. 33. How do you note changes on a drawing?

On tracing with date	32
New tracing and new number	17
Put a circle around old figure and write new figure beside it with date	8
Make new tracing	5
Red ink with date	8
Use rubberstamp "Revised" with date, and indicate changes on record print	28
Use change card system	1
Special forms for purpose. Change made in a book with date. New prints made to replace. In place at title with draftsman's initials and date	8

Q. 34. Do you place dimensions to read from bottom and right hand, or all to read from bottom, or how?

Bottom and right hand	103	From bottom only	2
No fixed rule	2		
From R to L and bottom to top	1		

Q. 35. Do you always make a table to contain the bill of material?

Yes.........	49	No..........	25	Not always..	5
Usually..............	1	Use separate bill.......	32		

Bills on general drawings only. On details number is marked on piece.

"No, but it is advisable to do so." "Have abandoned that system."

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